EPRI

A Code for Analyzing Coolant and Offgas Activity in a Light Water Nuclear Reactor: Computer Manual

A Code for Analyzing Coolant and Offgas

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CHIRON for WINDOWS – User's Manual

A Code for Analyzing Coolant and Offgas Activity in a Light Water Nuclear Reactor

CM-110056

Computer Manual, June 1998

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REPORT SUMMARY

The CHIRON code meets the nuclear industry's need for a model that can estimate the number of failed fuel rods in the nuclear reactor cores of operating BWRs and PWRs. This PC-based tool—now available in WINDOWS format—provides this estimate by using coolant and/or offgas activity measurements. The WINDOWS version adds significant flexibility in terms of database capabilities and the code's use as a general activity release management tool. This user's manual provides a complete tutorial on the installation and operation of CHIRON as well as its various outputs.

Background

The CHIRON code for coolant and offgas activity data management and analysis contains three main elements: a database, a sample analysis module, and a trending analysis module. The database stores plant design data, cycle operational data, and activity sample data for multiple cycles along with measurement units and unit conversion information. The database also stores selected analytical results along with model parameter settings. The sample analysis module performs a "release-to-birth versus lambda" least squares fit for determining the number of failed fuel rods in the core. The trending analysis module provides an overview of the variation of a large number of measured activities and calculated parameters during a chosen time period.

Objectives

To provide a tutorial for the installation and operation of CHIRON and present an overview of the code's enhanced capabilities in the WINDOWS version.

Approach

The project team created a primary user interface featuring enhanced database selection capabilities, expanded output options, user-defined plant configuration and model settings, options for setting the units of the input data, and open database analysis capabilities for user-defined plant cycles. The team also increased the ease of editing and printing of plots and analysis reports. Finally, they enhanced CHIRON's potential for handling a larger number of "reactor- soluble" isotopes as well as an expanded series of isotopic activity expressions. Each of these changes expands the use of CHIRON as a general activity release management tool. They created this user's manual to support the enhanced CHIRON WINDOWS version.

Results

The CHIRON Main Window is the operating base from where control can be passed to other windows and/or dialog boxes in response to user selections. In specific, CHIRON features

- An extensive BWR/PWR failed fuel database
- A general failure model and a combined failure model specifically developed to address the low power failure problem, with emphasis on identification of the failed fuel power level
- Capabilities for analyzing three groups of fission products, including the noble gases, the iodines, and the reactor solubles
- Use of fitted coefficients in conjunction with coolant sample input
- Calculations that include background activity from tramp fuel and recoil
- Custom configuration capabilities for individual plants
- Capabilities for processing a variety of input data and performing single sample and batch sample analysis
- Outputs of isotopic ratios as well as outputs conforming to requirements of the Institute of Nuclear Power Operations (INPO) fuel reliability index
- Outputs in the form of screen plots and analysis reports for individual samples, screen plots for trending analysis, and batch export files for transfer of data to a spreadsheet or alternative applications

This user's manual provides guidance on the installation of CHIRON 3.0, data entry methods, and the process for converting previous CHIRON databases. It also describes forms of output, structure and contents of the CHIRON database, the theory behind CHIRON calculations, and error message instructions. CHIRON runs on any PC-based system with WINDOWS 3.1 or higher.

EPRI Perspective

Both the potential and flexibility of the CHIRON 3.0 WINDOWS version have been significantly enhanced relative to previous DOS versions. Use of this version will enable utilities to more accurately assess failed fuel rods on a sample-by-sample or batch basis and produce outputs in a form that will enable them to more effectively manage general activity releases and fuel failures.

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Interest Category

Fuel assembly reliability and performance

Keywords

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Fuel rods
Failure analysis
Activity release

ABSTRACT

The CHIRON code is a PC based Coolant and Offgas Activity Data Management and Analysis Tool, now available under WINDOWS. The code contains three main elements: A database, a sample analysis module, and a trending analysis module. The database stores plant design data, cycle operational data and activity sample data for multiple cycles, along with measurement units and unit conversion information. The sample analysis module performs a "Release-to-Birth versus Lambda" least squares fit, from which conclusions are made regarding the number of failed fuel rods in the core. The trending analysis module provides an overview of the variation through a chosen time period of a large number of measured activities and calculated parameters. A special calculation provides the Fuel Reliability Indicator, prescribed by the Institute for Nuclear Power Operations. Selected analytical results are also stored in the database, along with the model parameter settings used to produce the analyses. CHIRON accepts keyboard input on a sample-by-sample basis, or batch input from an ASCII-formatted file. Likewise, sample analysis and database storage can be performed in single-sample or batch mode. The CHIRON output consists of screen plots and analysis reports for individual samples, screen plots for trending, and batch export files for transfer of data to a spreadsheet or other alternative application. All plots and text-file reports can be printed, using the available WINDOWS facilities. The potential and flexibility of the CHIRON WINDOWS version have been significantly enhanced relative to previous DOS versions. The capability of the database to handle units and store model parameter settings along with the samples is one example of an enhancement to CHIRON. The ease with which editing and printing of plots and analysis reports can be performed is another. Furthermore, CHIRON now has the potential to handle a larger number of "reactor soluble" isotopes, as well as an expanded series of isotopic activity expressions, which greatly expands the use of CHIRON as a general activity release management tool.

ACKNOWLEDGMENTS

The CHIRON development was initiated by EPRI in 1987, as a logical continuation of the efforts of the ANS 5.3 Standards Committee. The actual development of the code was undertaken by S. Levy Incorporated.

We would like to acknowledge the early contributions of Carl Beyer of Battelle Pacific National Laboratories, who was appointed by the ANS 5.3 Standards Committee to compile, sort and analyze the initially collected raw data and advised the S. Levy Incorporated developers.

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1

INTRODUCTION AND OVERVIEW

In this section, a brief overview is given of the problem CHIRON attempts to solve, the means available for the solution, and the approximations that need to be made to achieve the solution.

An overview of CHIRON's notable features and capabilities is also provided in this section. A flow diagram is included to illustrate the main components of the CHIRON program and the path the user will follow when using the code.

1.1 Identification of Problem

In the nuclear industry there is a need for a model that can estimate the number of failed fuel rods in the nuclear reactor cores of boiling water reactors (BWR) and pressurized water reactors (PWR) during plant operation.

1.2 Solution Methods

CHIRON provides an estimate of the number of failed fuel rods by using coolant and/or offgas activity measurements. The method of analyzing the activity samples incorporates a theoretical model of the fission product release characteristics of chemically similar nuclides (e.g., iodine nuclides and noble gas nuclides) coupled with an empirical relationship based upon the evaluation of numerous release samples from various BWR and PWR reactor cycles.

CHIRON performs a failure analysis with the use of two models: the General Failure Model and the Combined Failure Model. Three groups of fission products are analyzed by CHIRON. These groups include the noble gases, the iodines and the reactor solubles. CHIRON has been prepared to include alternative analyses to handle other subgroups in the future.

The noble gases represent xenon and krypton isotopes for a total of seven members. The noble gases are frequently referred to in CHIRON as "offgas", because of the method by which measurements are obtained in a BWR. This terminology is used herein to refer to PWR noble gas coolant measurements as well.

There are five isotopes that represent the iodine group. Activity measurements of these isotopes are obtained from analysis of coolant samples in both BWRs and PWRs.

The reactor solubles consist of a large number of rather dissimilar isotopic species. These isotopes are partly fission products and partly originating from environmental impurities or reactor internals. CHIRON does not provide a direct correlation between the reactor soluble activity measurements and fuel failures, however, trending of one or more of these nuclides can often be of benefit in evaluating and tracking various aspects of fuel performance.

1.3 Empirical Failure Modeling

The General Failure Models are based on empirical fits to the large number of samples in the original database. The data used in the failure correlation was restricted to reactor power levels above 80 % of rated power, with most of the data lying near rated power. This is consistent with the fact that most failures reported during the time span of the database were pellet cladding interaction (PCI) failures, which tend to occur preferentially at substantial power levels. Consistently with these benchmarking conditions, the General Failure Models have proven to work quite well for BWRs, for which failures seem to occur more frequently at medium to high power levels. Unfortunately, the PWR models have been somewhat less successful, due to the relatively frequent occurrance of low power fretting failures. The model improvements for the 1992 version helped to alleviate this problem, but the most effective approach to predicting low power failures is the Combined Failure Model, that has been incorporated in the current version of CHIRON.

The Combined Failure Model was specifically developed to address the low power failure problem. The specific advantage of this model is the identification of the failed fuel power level. The model is based on the physical observation that the isotopic diffusion responds differently to temperature changes for offgas and iodines. The difference in isotopic diffusion between offgas and iodine samples has been correlated to fuel failure data over a wide range of rod power for both BWRs and PWRs. The resulting Combined Failure Model provides acceptable fuel failure estimates for rod operating conditions that have traditionally been difficult to evaluate.

1.4 CHIRON Logic Flow

Figure 1-1 shows a simplified flow diagram of CHIRON. The diagram emphasizes the dataflows, conversions, analyses, and data storage features.

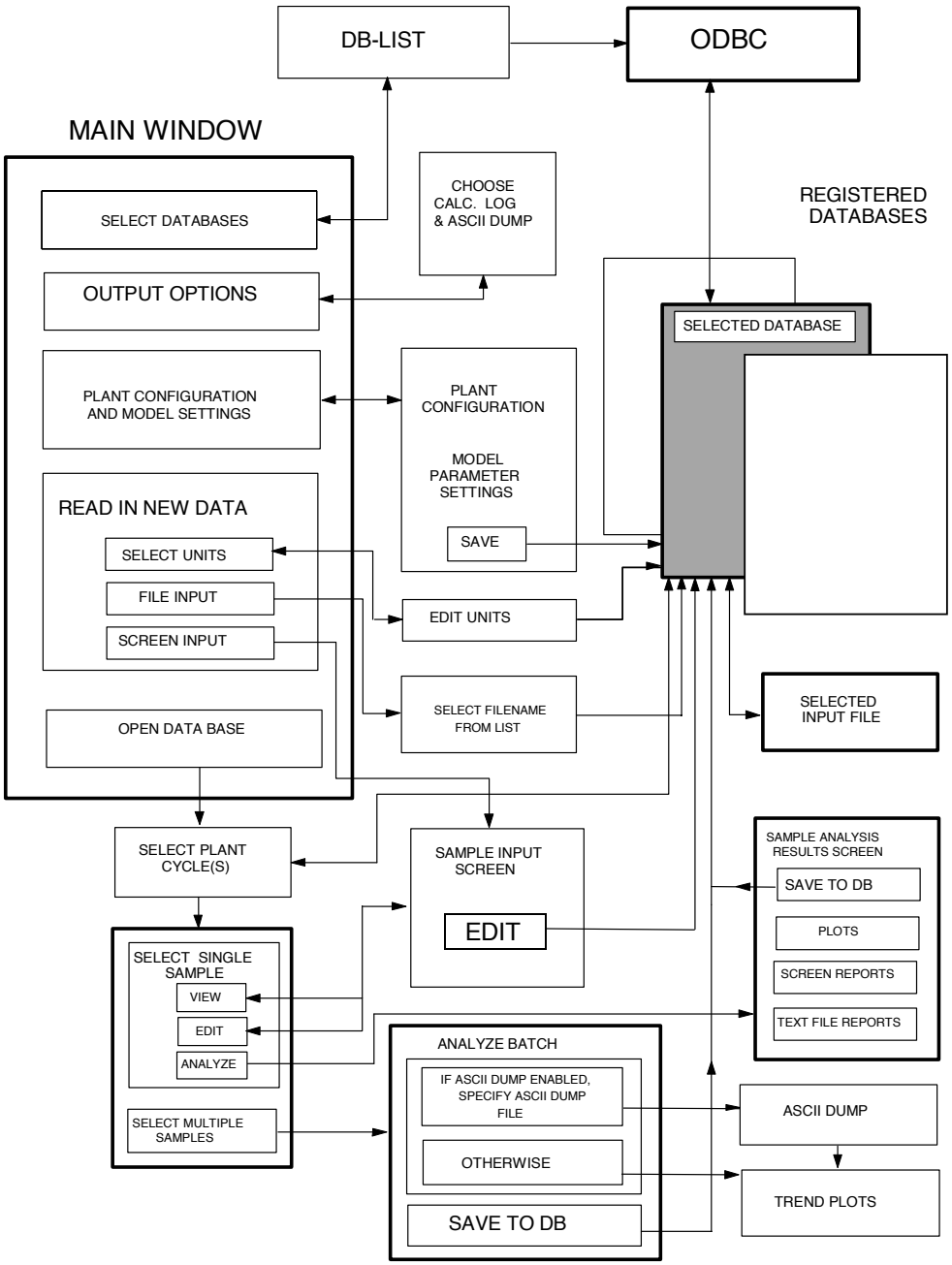

Figure 1-1
CHIRON 3.0 Logic Flow Diagram

The primary user interface for CHIRON 3.0 is labeled as the Main Window in the bold frame on the left of Figure 1-1. From this window, five principal actions may be taken as described below.

1) Database Selection. CHIRON allows the selection of any one of the pre-registered databases, connected to the program through the ODBC interface. The Database Selection is available from the main menu item "Data".

2) Output Options. The user may define certain settings that control the availability of (1) a calculation log file and (2) the feature of exporting data to an external application (the "ASCII Dump" feature). The Output Options are available from the main menu item "Options".

3) Plant Configuration and Model Settings. The user defines the set of design and operational parameters (the configuration data) that apply to each plant-cycle to be analyzed. The sets of plant-cycle configuration data are stored in the database under their plant-cycle IDs. The Plant Configuration Settings are available from the main menu item "Options".

4) Read in New Data. When new sample data is entered into the selected database, the user is given the option to set the units of the input data. The units selected will then apply to all subsequently entered samples. Data may be read in from a data file or it may be entered in screen form, one sample at a time. In either case, the sample data must refer to an existing plant-cycle ID configuration. The New Data option is available from the main menu item "Data".

5) Open Database. When analyzing sample data , the user may open the selected database, then proceed to select the plant-cycle(s) for which samples will be analyzed. If a single sample is selected, the data may be viewed and edited prior to analyzing. If multiple samples (batch) are selected, the view/edit option is not available. The analysis data will always be stored in the database, overwriting any previous results. When the analysis has been completed, the user may view the batch analysis results by means of the trend plotting option. The Open Database option is available from the main menu item "Data".

1.5 Features and Capabilities

A list of CHIRON's main features and capabilities is given below.

- Extensive BWR/PWR failed fuel database
- Uses fitted coefficients in conjunction with coolant sample input
- Calculations include background activity from tramp fuel and recoil
- Allows custom configuration for individual plants
- Handles variety of input data

- Performs single sample and batch sample analysis
- Outputs INPO fuel reliability index
- Outputs isotopic ratios
- Handles data inputs in numerous unit formats – program converts to standard units used by program
- Generates seven different plots
- Generates eight different reports
- Plots and reports can be viewed on screen
- Ability to print plots for presentation purposes
- Printable QA reports

WINDOWS provides the code framework in the form of windows and dialog boxes. The CHIRON Main Window is the operating base from where control can be passed to other windows and/or dialog boxes in response to the user's selections. The windows and dialog boxes are largely self-explanatory, but will be explained in later sections of this manual.

Detailed instructions on the installation of CHIRON 3.0 and a short tutorial are provided in Section 2 of this manual. The methods used to enter data into CHIRON are discussed in Section 3. The various forms of output produced by CHIRON are presented in Section 4. The structure and contents of the CHIRON database are described in Section 5. The process for converting previous CHIRON databases is also discussed in Section 5. Section 6 explains the theory behind the CHIRON calculations. Section 7 provides a list of error messages generated by CHIRON and instructions on what to do if you encounter error messages. References for this manual are contained in Section 8.

This manual also includes several appendices containing useful information on specific areas of the CHIRON code. Appendix A lists the files that are installed by CHIRON. Appendix B contains the format for file-read input. Appendix C shows a sample QA Analysis Report generated by CHIRON. Appendix D contains the format of the ASCII dump files that are contained on the distribution disk. Appendix E contains six tables that list the format of the CHIRON database tables.

2

GETTING STARTED

2.1 System Requirements

CHIRON is a 16-bit WINDOWS application, developed under WINDOWS 3.1 with no use of the Win32s libraries. CHIRON 3.0 for WINDOWS runs under WINDOWS 3.1, WINDOWS 95 and WINDOWS NT operating systems.

The following are the system requirements for installation and efficient use of CHIRON 3.0 for WINDOWS:

- A PC, model 486 or later, with minimum processor speed 50 MHz.
- A WINDOWS operating system (3.1x, 95, or NT 4.0).
- A VGA monitor or better.
- 16 MB of RAM.
- A hard disk with 15 MB of free space for a "typical" installation. (The exact requirement will be displayed in a separate screen during the "custom" installation.)
- A 3.5" floppy drive.
- The CHIRON distribution package.

2.2 The CHIRON 3.0 Distribution Package

The CHIRON Version 3.0 distribution package consists of a set of three 3.5" diskettes, one of which is marked "Disk 1 of 3". This diskette includes the "Setup" program.

The distribution diskettes include a blank database, "chiblank.mdb", intended to form the basis for the user in developing his own, plant-specific database. In addition, the distribution includes three other databases: "chiron1.mdb", "chiron2.mdb" and "chiron3.mdb". These databases all contain test data designed to assist the user in getting acquainted with CHIRON and qualifying the installation.

2.3 Installing CHIRON from the Diskettes

Before starting the installation, the diskettes should be backed up and the backup copies stored in a safe place. Also close all programs on your WINDOWS system before starting the installation of CHIRON.

NOTE: These installation instructions are written for a WINDOWS 3.1x user. All illustrations in this manual represent the image one sees if using CHIRON 3.0 on WINDOWS 3.1x. For those users on WINDOWS NT or WINDOWS 95, the screens will be the same except for the following: 1) the text in the title bar will be left justified instead of centered , 2) the symbol used to close a window and adjust the size of the window are different between WINDOWS applications. Consult your WINDOWS user manual if you do not know how to close or adjust the window size in your particular application.

Follow the steps below to install CHIRON 3.0 on your computer.

1. Insert Disk #1, into the 3.5" floppy drive. For a WINDOWS 3.1x installation, select **"File"** from the Program Manager, then select **"Run"** from the drop-down menu. (For WINDOWS NT or WINDOWS 95, from the "Start" menu, choose Run.) Now, type "a:\setup.exe" into the "Command Line" box, with "a" representing the floppy drive on your computer. Change the "a" if your floppy drive is not drive a. Press "Enter" on the keyboard or click "OK" with your left mouse button.

2. The EPRI CHIRON program banner appears and then the first screen (the Welcome screen) of the installation process appears. The Welcome screen is shown in Figure 2-1. Click on "Next" to continue the installation.

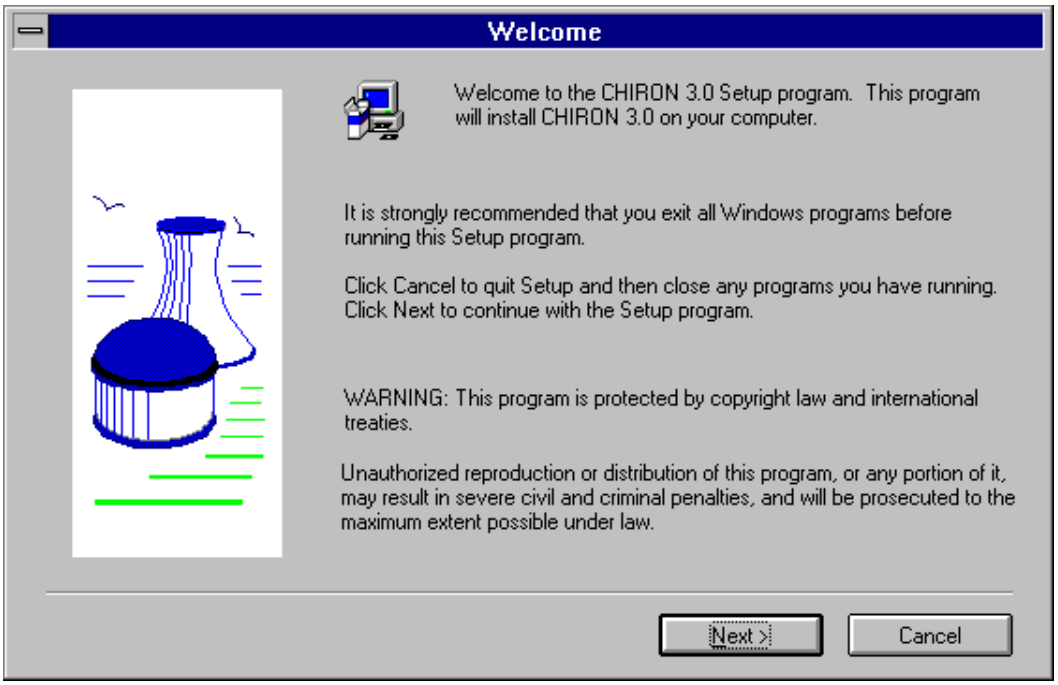
Welcome
Welcome to the CHIRON 3.0 Setup program. This program will install CHIRON 3.0 on your computer.
It is strongly recommended that you exit all Windows programs before running this Setup program.
Click Cancel to quit Setup and then close any programs you have running. Click Next to continue with the Setup program.
WARNING: This program is protected by copyright law and international treaties.
Unauthorized reproduction or distribution of this program, or any portion of it, may result in severe civil and criminal penalties, and will be prosecuted to the maximum extent possible under law.
Next >
Cancel

Figure 2-1
Welcome to CHIRON 3.0

3. Choose the destination location for the CHIRON 3.0 program file folder. The default location is drive C:\CHIRON30. Select an alternate drive if desired. Click "Next".

   Note: If CHIRON for WINDOWS has been previously installed on the user's system, choose the same target directory as the previous installation so that only one copy of the database will be installed. Folder names are restricted to eight characters to maintain compatibility with Windows 3.1x.

4. Select the installation type. Figure 2-2 shows the installation types available, i.e., typical, compact or custom.

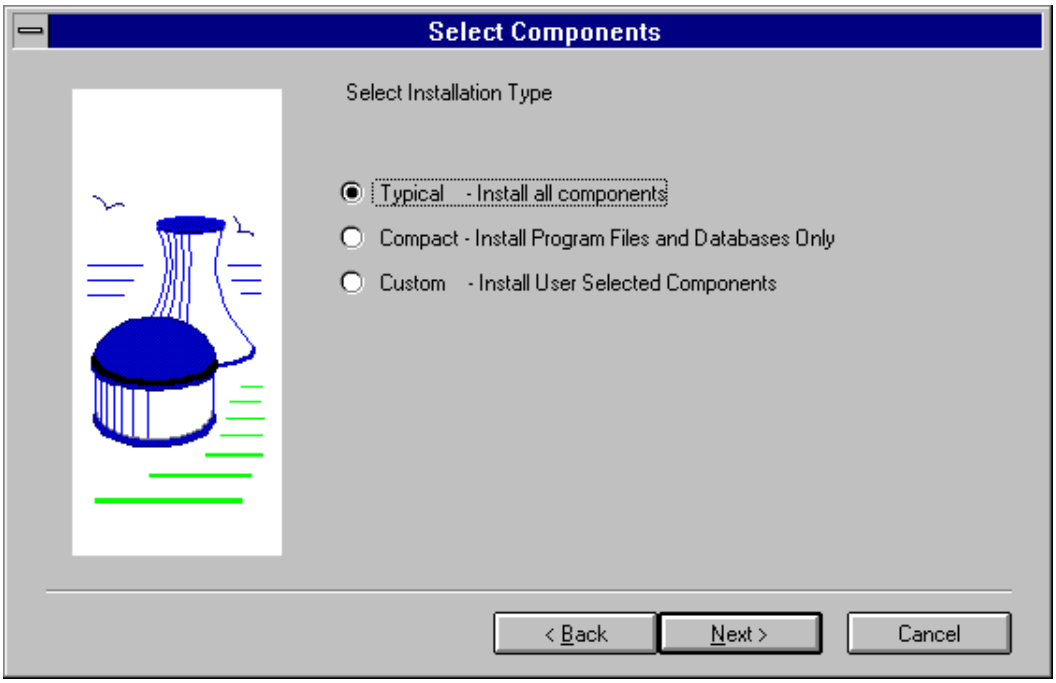
Select Components
Select Installation Type
Typical - Install all components
Compact - Install Program Files and Databases Only
Custom - Install User Selected Components
< Back
Next >
Cancel

Figure 2-2
Selecting Installation Type

A description of the three types of installation are provided below.

Typical Installation	All program files, sample database files, example files, readme files, ODBC drivers, etc. are installed. It is possible to perform a Typical Installation on top of an existing installation. The ODBC database registration will be performed afer the files are installed. The database registration can be bypassed by immediately clicking “Close” in the ODBC Administrator opening box (the ODBC Data Sources list box).
Compact Installation	Only the program files, database files and the readme file are transferred. The database setup and registration is skipped. Distribution databases will be overwritten, but their registration will not be affected. This option may be useful for installing a new version of CHIRON, or re-installing the program executable if this file were to have been corrupted by system malfunction.

Custom Installation	Any set or sets of files may be chosen for re-installation. An example of a Custom Installation would be to reinstall just the example files. The ODBC driver installation will be performed, followed by the call to the ODBC Administrator. By selecting no files to be transferred, the user is able to perform maintenance functions on the database system, such as re-registration of existing databases under different names, deleting databases from registration status, or adding databases to the registered set. It is also possible to perform database compaction from the ODBC Administrator. A database can be compacted into itself, or into a new file to be created. When "Custom" installation is chosen, the setup program will show an extra dialog box, allowing the user to check the file groups to be transferred. This screen also shows, for any selection made, the required disk space along with the available space on the chosen drive.

It is recommended that "typical" be selected for a first time installation. You select it by clicking on the radio button next to "typical".

5. A screen appears telling you that the ODBC and OLE Drivers are being updated. Click on "Next".

6. The next step is to select the program folder name. The setup program suggests the name "CHIRON 3.0" for the program group to appear in the WINDOWS Program Manager. Accept the default selection by clicking "Next".

   All the CHIRON program and database files are being copied to the target directory, along with certain test data files and a readme file. All the CHIRON ".dll" files, as well as all the required ODBC files (which includes the ODBC Microsoft Access Driver) are copied to the WINDOWS\SYSTEM directories. Older versions of these files will be replaced if they exist.

   This will take a few minutes. You will see bars on the screen showing the progress of the installation. You will be asked to insert disks 2 and 3 into the floppy drive when needed.

   NOTE: Should any of the installed .dll files already be found on your computer system as read only files, the program will prompt you to overwrite the file. Choose "yes". Also, if the chosen installation type requires more disk space than is available on the chosen drive, a message

will appear, flagging this condition. If this happens, click on "Cancel" to cancel the installation. A dialog box appears asking if you want to exit Setup. Click "Exit Setup". Either free space on the target drive or install CHIRON 3.0 on a different drive that has more free space.

7. After copying the files, the setup program automatically installs the ODBC driver, then opens the ODBC Administrator. At this point, the user must specify how the available databases are to be registered. This is done by responding to a series of dialog boxes in the ODBC Administrator.

   A. After an information box, the first dialog box to appear is the Data Sources list box as shown in Figure 2-3. During the initial CHIRON installation this box will probably be empty. It is possible that you have other programs on your computer that use ODBC and, therefore, have existing registered data sources. Once databases have been registered, the list of registered databases will appear in this box whenever you access this dialog box. Now we are going to add a database so click "Add". This opens the next box.

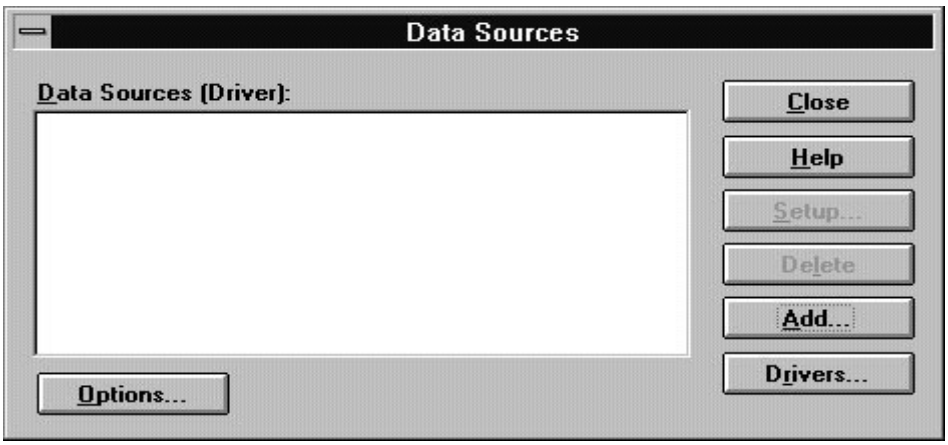

Figure 2-3
The Data Sources List Box Before Registering Databases

   B. A list of installed drivers is now displayed as shown in Figure 2-4. Since the "Microsoft Access Driver" was installed as part of the CHIRON 3.0 installation steps above, it will appear in the list. There may or may not be other drivers as well, depending on past installations on the computer system. Select the "Microsoft Access Driver (*.mdb)" by highlighting it and clicking "OK".

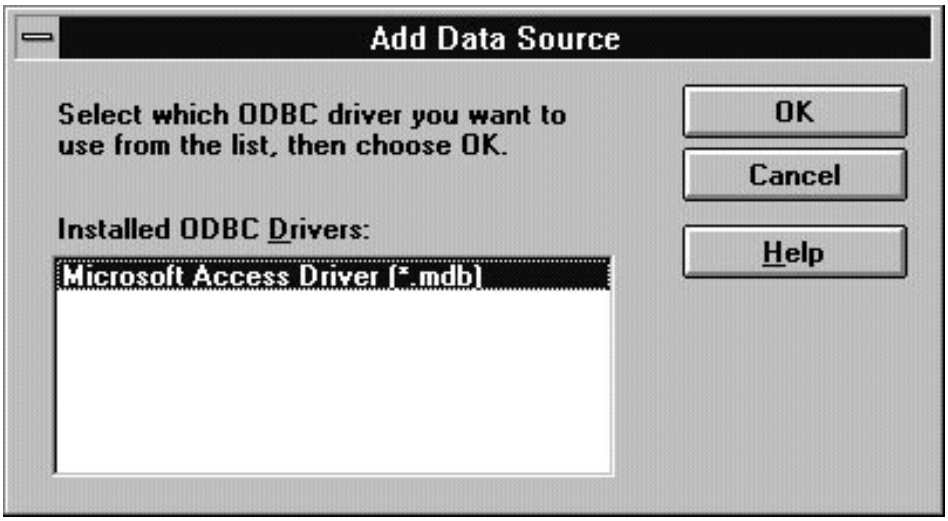

Figure 2-4
Selecting ODBC Driver

C. The next box that appears requests the Data Source Name. Enter "CHIRON DB". Your screen should look like Figure 2-5. Click **"Select"**. **NOTE: There must always be a valid database that is registered under the name "CHIRON DB" for CHIRON 3.0 to function properly. This is the default Data Source name. On starting up, CHIRON will always look for a database registered under this name. After starting the program, the user may select any alternative, registered database.**

Figure 2-5
Data Source Name Definition Box

D. The Database File Name selection box appears next. Under directories, select the target directory (e.g., C:\CHIRON30). The CHIRON 3.0 installation process places four valid database files: "chiblank.mdb", "chiron1.mdb", "chiron2.mdb" and "chiron3.mdb" in this directory. Choose the database file "chiron1.mdb" as the Database Name. Your screen should look like the one shown in Figure 2-6. Click **"OK".** This takes you back to the Data Source name selection box. Note that the selected database is now C:\CHIRON30\CHIRON1.MDB, assuming you installed in the sample target directory. Click "OK" again.

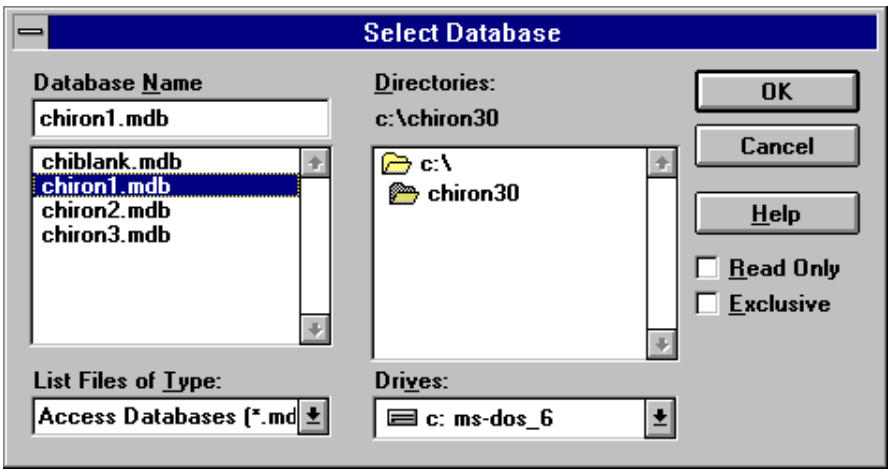

Figure 2-6
Database File Name Selection Box

8. The first database, "chiron1.mdb" has now been registered under the Data Source name "CHIRON DB", to be used with the "Microsoft Access Driver". The name "CHIRON DB" appears in the list of registered databases as shown in Figure 2-7.

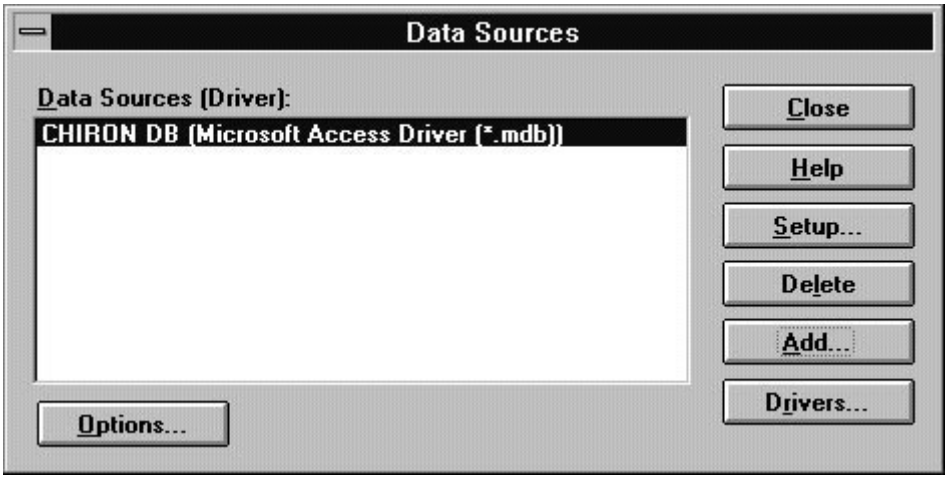

Figure 2-7
Registered Database and Driver Designation

At this point, it is desirable to add additional databases to the database registry. Choose "Add" and follow steps 7.B. through 7.D. above again to register the next database, "chiblank.mdb" as Data Source "CHIBLANK DB", to be used with the "Microsoft Access Driver". **(NOTE: The Data Source name "CHIBLANK DB" is suggested for this example installation exercise. Any other name compatible with the ODBC convention may be chosen.)** Then, register the remaining two databases "chiron2.mdb" and "chiron3.mdb" as Data Sources "CHIRON2 DB" and "CHIRON3 DB", respectively, to be used with the "Microsoft Access Driver".

Verify that all four data source names now appear as shown in Figure 2-8. Choose "Close" to proceed with the CHIRON installation.

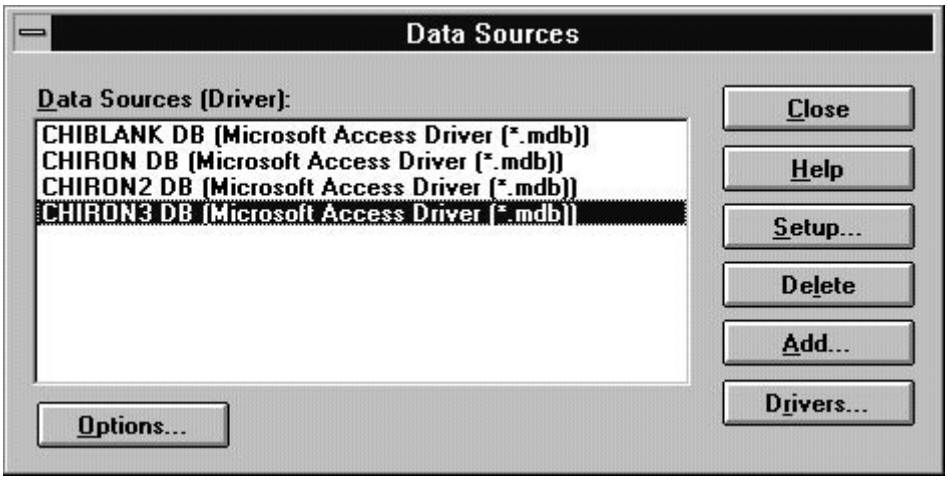

Figure 2-8
The Data Sources List Box Showing All Databases Required

9. The final installation window appears as shown in Figure 2-9 to indicate that the setup program is complete. You may be prompted to reboot your computer now. If so, select "Yes". Click on "Finish" to complete setup. The installation program installs several files on your computer system. For a list of files that are installed, their directory location and purpose, see Appendix A.

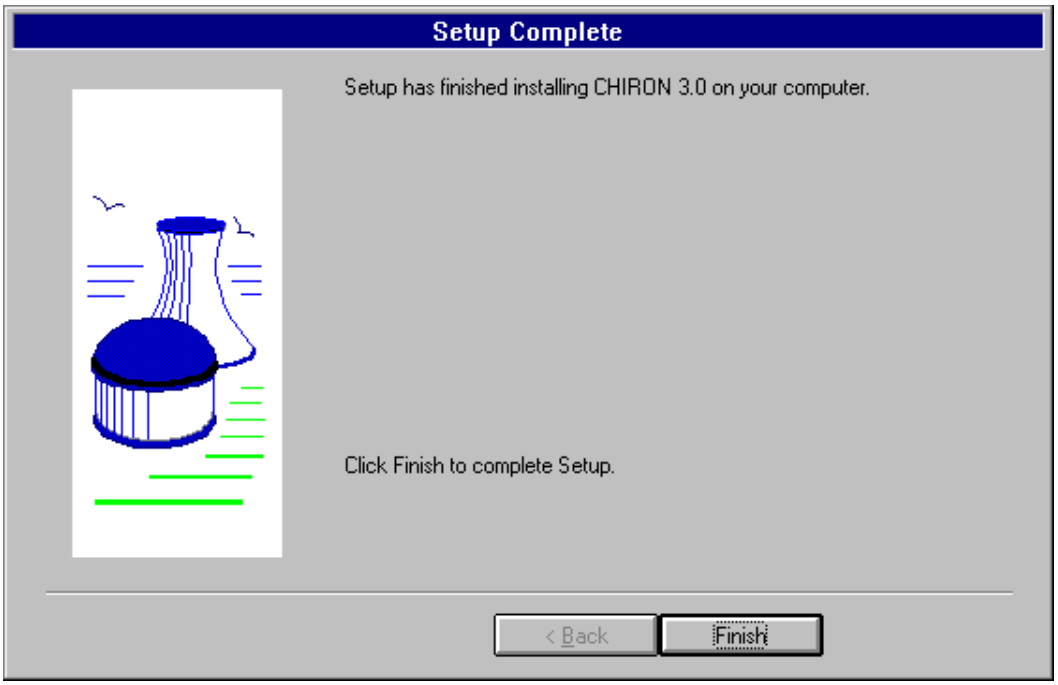

Figure 2-9
Setup Complete

10. A program group has been created during the installation that contains four items (see Figure 2-10):

    - The CHIRON 3.0 Program Icon,
    - The Database Conversion Program Icon,
    - The Readme File Icon, and
    - The Uninstall Icon.

    The CHIRON Program Icon is used to start the CHIRON program. The Database Conversion Program Icon is used when you want to convert databases from older versions of CHIRON. The process for converting databases is explained in Section 5. The Readme File Icon accesses the CHIRON Readme File which contains information which is not found in this User Manual and that may apply to a specific application of CHIRON. The Uninstall Icon is used to remove the CHIRON program files from your computer system.

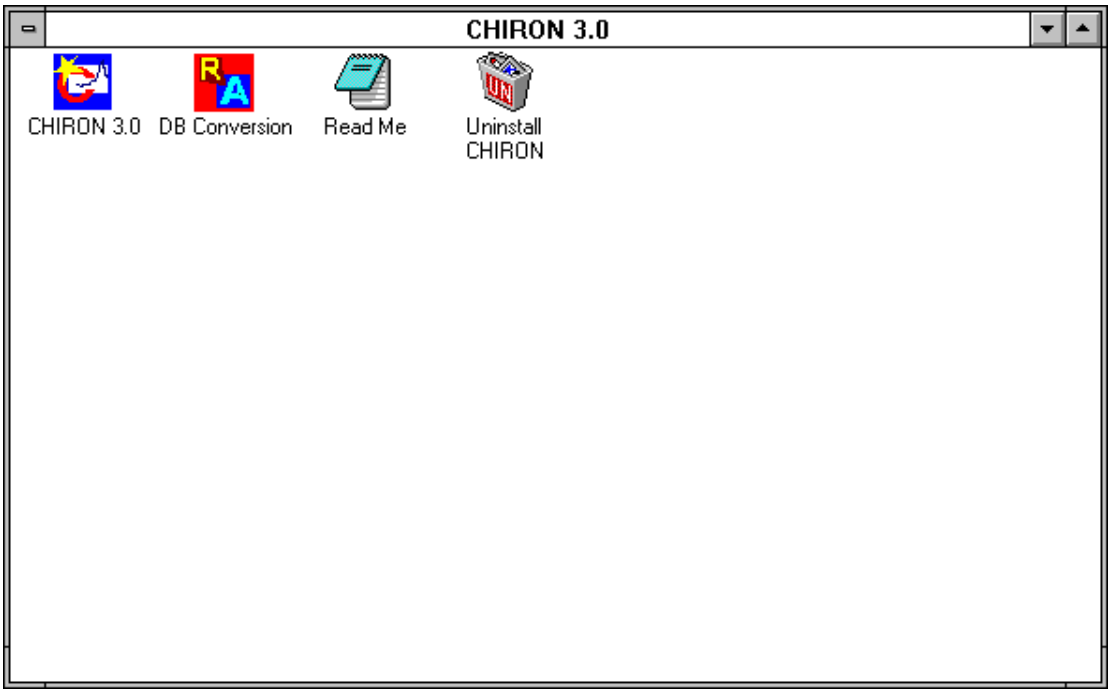

Figure 2-10
CHIRON Program Group

2.4 Description of the Sample Databases

Included with the CHIRON 3.0 distribution package are four databases: A blank database, “chiblank.mdb” and three test databases, having filenames

"chiron1.mdb", "chiron2.mdb", and "chiron3.mdb". The blank database is a pre-formatted CHIRON database, containing all the empty tables that a user needs to create his own database. The blank database contains one plant configuration entry, "Plant-nn". This entry has been included to serve as a template for additional entries.

The test databases have the following contents:

"chiron1.mdb": Two BWR cycles, Cycles 5 and 7 of Plant "BWR01"

"chiron2.mdb": One BWR cycle, Cycle 11 of Plant "BWR02"

"chiron3.mdb": One PWR cycle, Cycle 9 of Plant "PWR01"

Additional database files may be created by copying any existing database (normally the blank database) to a new filename. See Section 5 for details on how to create a new database in CHIRON.

2.5 Running CHIRON 3.0 Tutorial

This subsection will provide a sample exercise to familiarize you with some of the CHIRON features and show you how to navigate in the CHIRON windows. Follow the steps below to learn how to run CHIRON.

Step 1: Starting CHIRON 3.0

To start CHIRON 3.0, double click on the CHIRON 3.0 for WINDOWS icon in the WINDOWS Program Manager. A CHIRON 3.0 program banner will appear briefly followed by the main program window as shown in Figure 2-11.

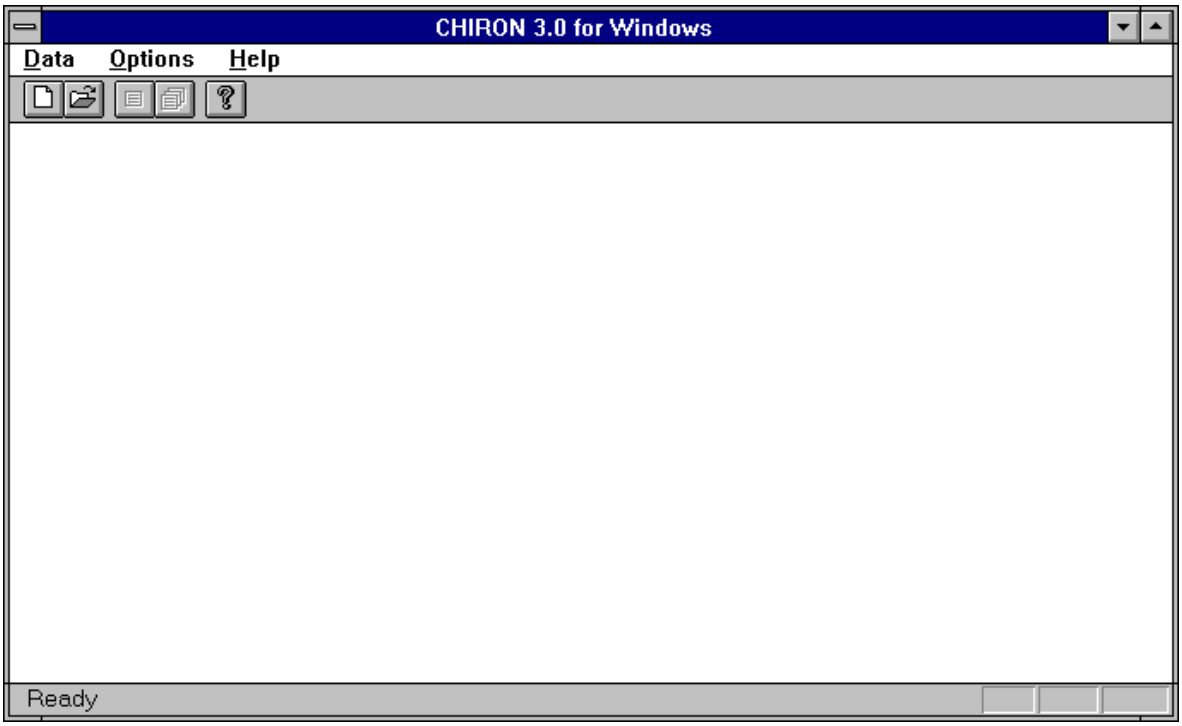

Figure 2-11
CHIRON Main Window

Step 2: Selecting a Database

When CHIRON starts, it automatically opens the database registered under the default name "CHIRON DB". If the installation procedure in Subsection 2.3 has been strictly followed, the selected database is "chiron1.mdb", containing data from BWR01 Cycles 5 and 7.

Click on "Data". The Data drop-down menu appears, see Figure 2-12. Click on "Select Data Source".

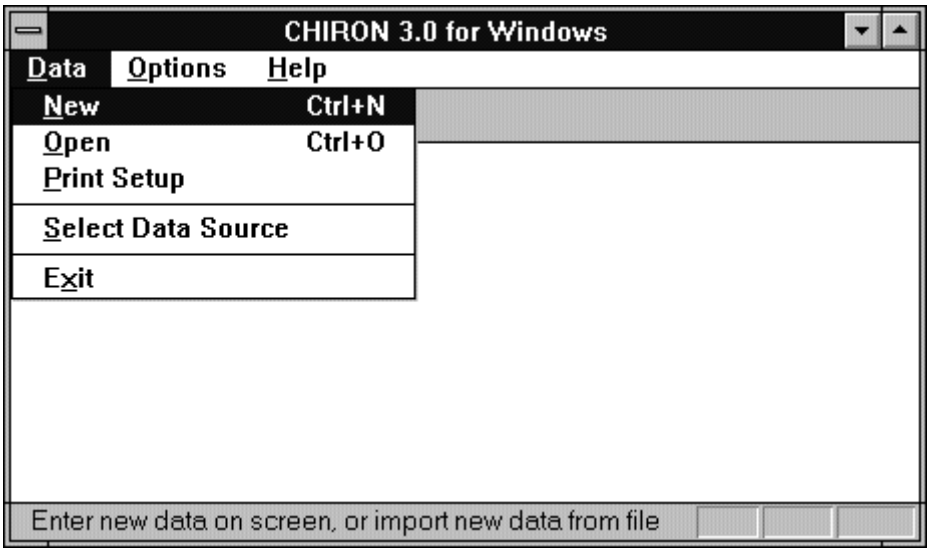

Figure 2-12
CHIRON Main Window – Data Drop-Down Menu

The Select Data Source dialog box appears showing the list of registered databases. Click on Data Source "CHIRON2 DB", (see Figure 2-13) then click OK. The program returns to the Main Window.

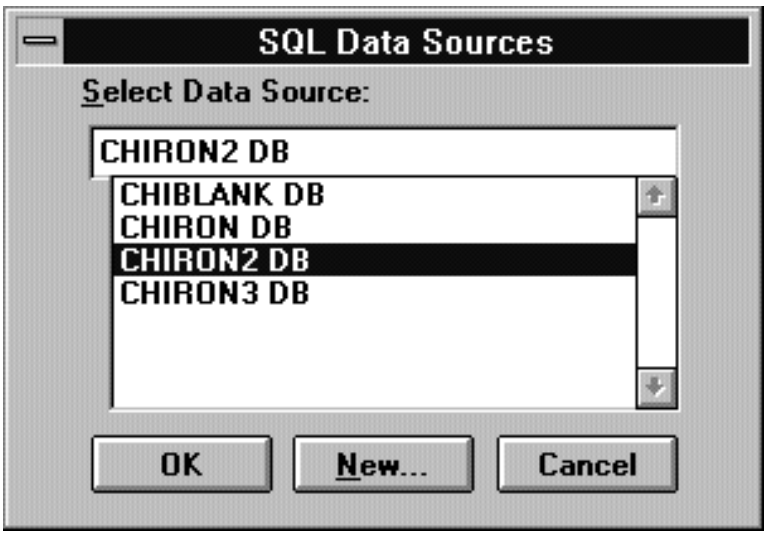

Figure 2-13
The Data Sources Screen

Step 3: Selecting Output Options

From the Main Window select "Options". Then choose "Output" from the drop-down menu. The dialog box for selecting the output options appears.

In this screen, there are two output options to choose from: 1) a calculation log file and 2) an ASCII dump file. When selected, the option(s) remains in effect until changed during a CHIRON session, or until the program is exited. You may select one, both or none of the options from this box.

1. Enable calculation log file for single sample analysis. If you check this box, then a text file named "chicalc.log" will be generated at the completion of each single sample analysis. The "chicalc.log" file will be placed in the CHIRON30 folder. This file can be used to retrieve all details of the calculational sequence for the last calculated sample. It may be very large, on the order of 60 printed pages. This option is not available when running samples in Batch Analysis mode. Once created, the log-file may be accessed with the use of a text editor. When a new sample analysis is performed, the previous chicalc.log file is overwritten. The default choice for this option is no calculation log file.

2. Enable ASCII Dump files for batch analysis. If you check this box, then ASCII dump files will be written and placed in the CHIRON30 folder every time a batch sample analysis is performed. The default choice for this option is no ASCII Dump file.

For this exercise, click (check) on both boxes. Your screen should look like the one shown in Figure 2-14. Click OK. The program returns to the main window.

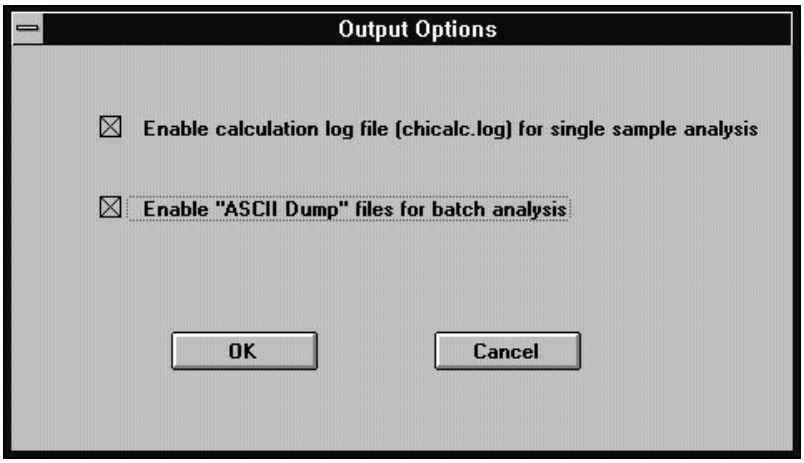
Output Options
Enable calculation log file (chicalc.log) for single sample analysis
Enable "ASCII Dump" files for batch analysis
OK
Cancel

Figure 2-14
Output Options Dialog Box

Step 4: Selecting Plant Cycle Configuration

From the CHIRON 3.0 Main Window, click on Options. Select "Plant Configuration" from the drop-down menu, then select "Edit Existing Plant". The Edit Plant-Cycle Configuration dialog box appears. Select "BWR02-11" from the Plant Cycle ID list in the upper left corner of the box. Notice the data found in the rest of the box changes to represent the BWR02-11 plant. Now find the place in the lower right section where "Perform Solubles Calculation" is listed as a model option. Select it by clicking in the box. Your screen should look like Figure 2-15. Click OK.

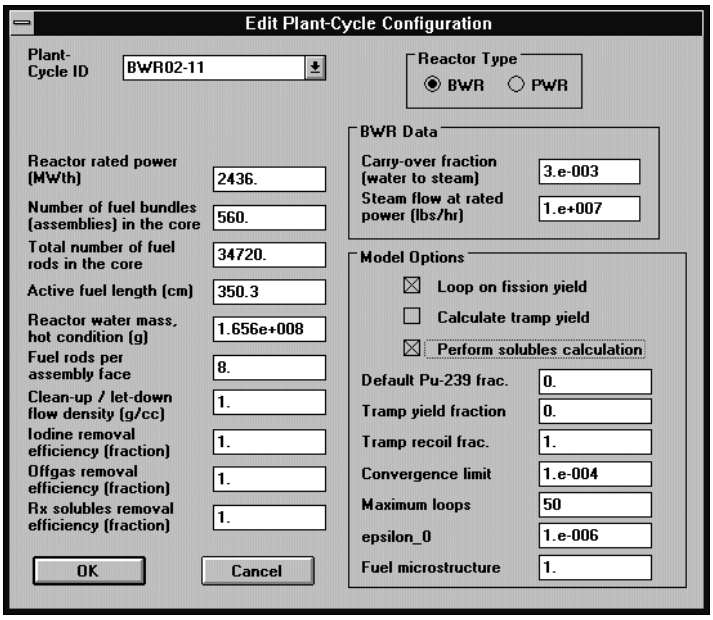

Figure 2-15
The Edit Plant-Cycle Configuration Dialog Box

Step 5: Select Plant Cycle

Select "Data" from the Main CHIRON 3.0 window, then select "Open". The Plant Select dialog box appears as shown in Figure 2-16.

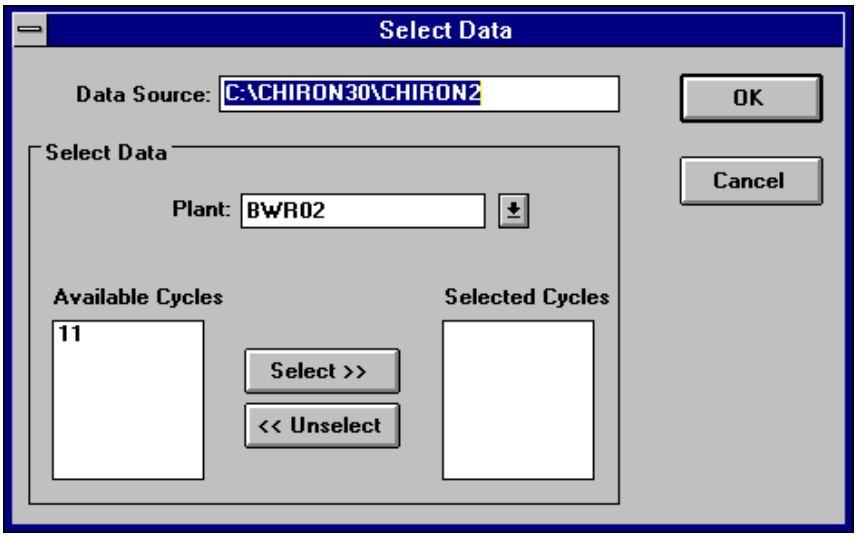

Figure 2-16
The Plant-Cycle Selection Dialog Box

In this dialog box, there is only one plant name, BWR02, available in the list box. Highlight the only available cycle (Cycle 11), then click "Select" (the number 11 moves over to the right hand box), then click "OK".

Step 6: Selecting Samples to Analyze

The dialog box appears as shown in Figure 2-17. As we go through the exercise using this box note that there is an extended menu bar at the top containing four new menu items: Sample, Select, Analysis and Trending. Most of the options under these menu items may be found on the various buttons on this box. For instance, the Select menu item contains the "Toggle Status", "Time-Select Batch" and "Clear All Selections" options. These options also appear as buttons at the bottom of the box. Under the Sample menu, there are a few items that are not found elsewhere on the box. These items include "Delete Sample", "Delete Batch" and "Add Sample". To use any of these particular options, highlight or mark a sample and then choose the option you desire.

The Sample Select dialog box contains a scrollable list of several hundred samples. Use the scroll bar on the right side of the table to scroll through the list of samples. Scroll until the top record in the box is as shown in Figure 2-17.

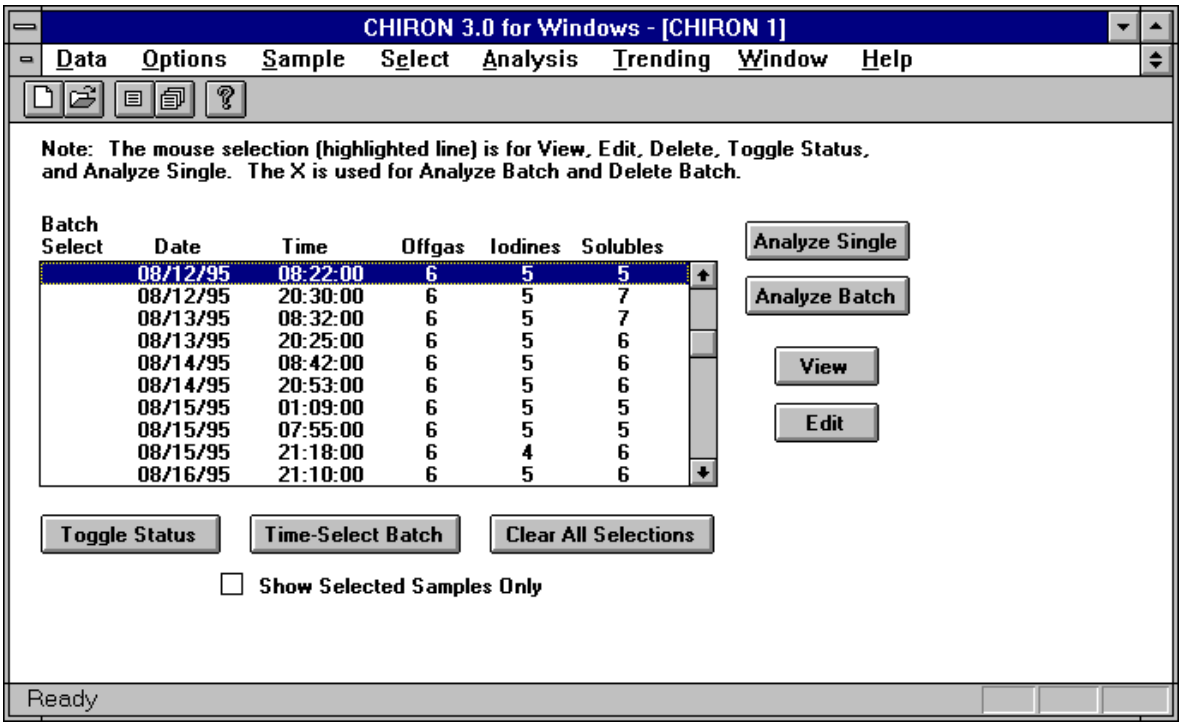
CHIRON 3.0 for Windows - [CHIRON 1]
Data Options Sample Select Analysis Trending Window Help
Note: The mouse selection (highlighted line) is for View, Edit, Delete, Toggle Status, and Analyze Single. The X is used for Analyze Batch and Delete Batch.
Batch Select
Date Time Offgas Iodines Solubles
08/12/95 08:22:00 6 5 5
08/12/95 20:30:00 6 5 7
08/13/95 08:32:00 6 5 7
08/13/95 20:25:00 6 5 6
08/14/95 08:42:00 6 5 6
08/14/95 20:53:00 6 5 6
08/15/95 01:09:00 6 5 5
08/15/95 07:55:00 6 5 5
08/15/95 21:18:00 6 4 6
08/16/95 21:10:00 6 5 6
Analyze Single
Analyze Batch
View
Edit
Toggle Status
Time-Select Batch
Clear All Selections
Show Selected Samples Only
Ready

Figure 2-17
Sample Select Dialog Box

Use the mouse to first highlight, then x-mark (by clicking the "Toggle Status" button or by double clicking the mouse button on the sample) the samples dated 8/13/95 at time 20:25:00, 8/14/95 at 20:53:00, and 8/15/95 at 21:18:00. Now, use the mouse to highlight the sample dated 8/12/95, time 20:30:00.

The screen should now look like Figure 2-18. The list shows that the highlighted sample has 6 offgas activities, 5 iodines activities, and 7 solubles activities.

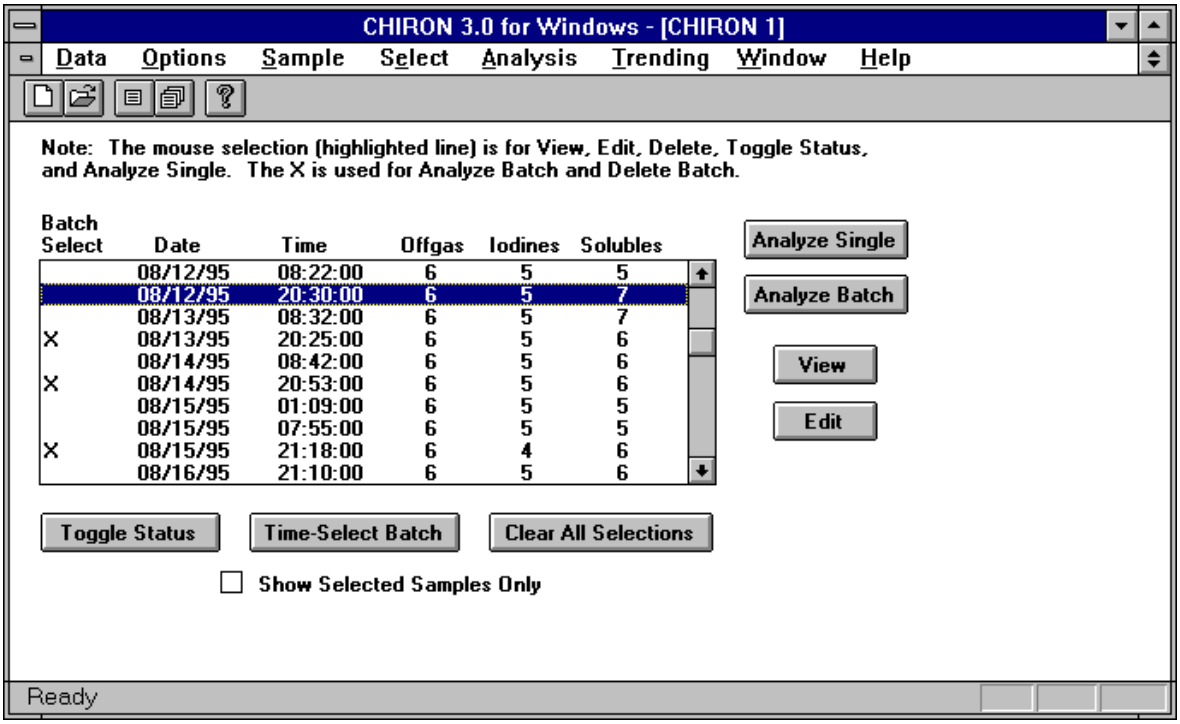
CHIRON 3.0 for Windows - [CHIRON 1]
Data Options Sample Select Analysis Trending Window Help
Note: The mouse selection (highlighted line) is for View, Edit, Delete, Toggle Status, and Analyze Single. The X is used for Analyze Batch and Delete Batch.
Batch Select
Date
Time
Offgas
Iodines
Solubles
08/12/95 08:22:00 6 5 5
08/12/95 20:30:00 6 5 7
08/13/95 08:32:00 6 5 7
X 08/13/95 20:25:00 6 5 6
08/14/95 08:42:00 6 5 6
X 08/14/95 20:53:00 6 5 6
08/15/95 01:09:00 6 5 5
08/15/95 07:55:00 6 5 5
X 08/15/95 21:18:00 6 4 6
08/16/95 21:10:00 6 5 6
Analyze Single
Analyze Batch
View
Edit
Toggle Status
Time-Select Batch
Clear All Selections
Show Selected Samples Only
Ready

Figure 2-18
Box Showing Selected Samples

Step 7: Performing Single Analysis of Selected Samples

There are two types of analysis that can be performed: 1) Analyze Single or 2) Analyze Batch. Analyze Single analyzes the highlighted sample. Analyze Batch analyzes the X-marked samples only. For this tutorial, choose "Analyze Single". The highlighted sample is analyzed. Because the option for "Perform Solubles Calculation" is set, both offgas/iodines and solubles are analyzed. Note: An information message may appear that indicates that the Sum of 6 will be used for this calculation. Click "OK" to continue.

Step 8: Selecting Plots and Reports

After performing the analysis in Step 7 above, a summary screen report appears. From the menu bar at the top, either "Plots" or "Reports" can now be selected. Figure 2-19 shows the drop-down menu list of types of plots that are available in CHIRON. Click on the various plots to view the result.

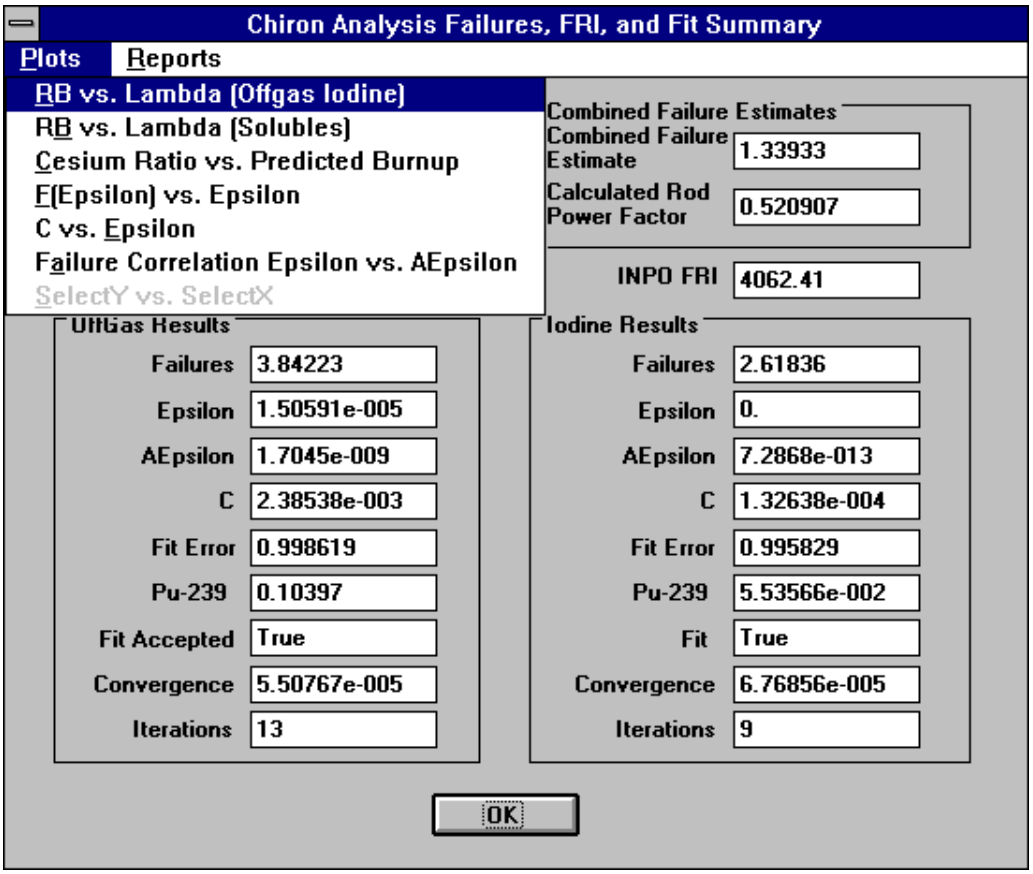

Figure 2-19
List of Available Plots

Figure 2-20 shows the drop-down menu list of types of reports that are available in CHIRON. Click on the various reports to view the generated report. Detailed descriptions of CHIRON plots and reports are provided in Chapter 4 of this document. Close the Fit Summary Report screen by clicking on OK.

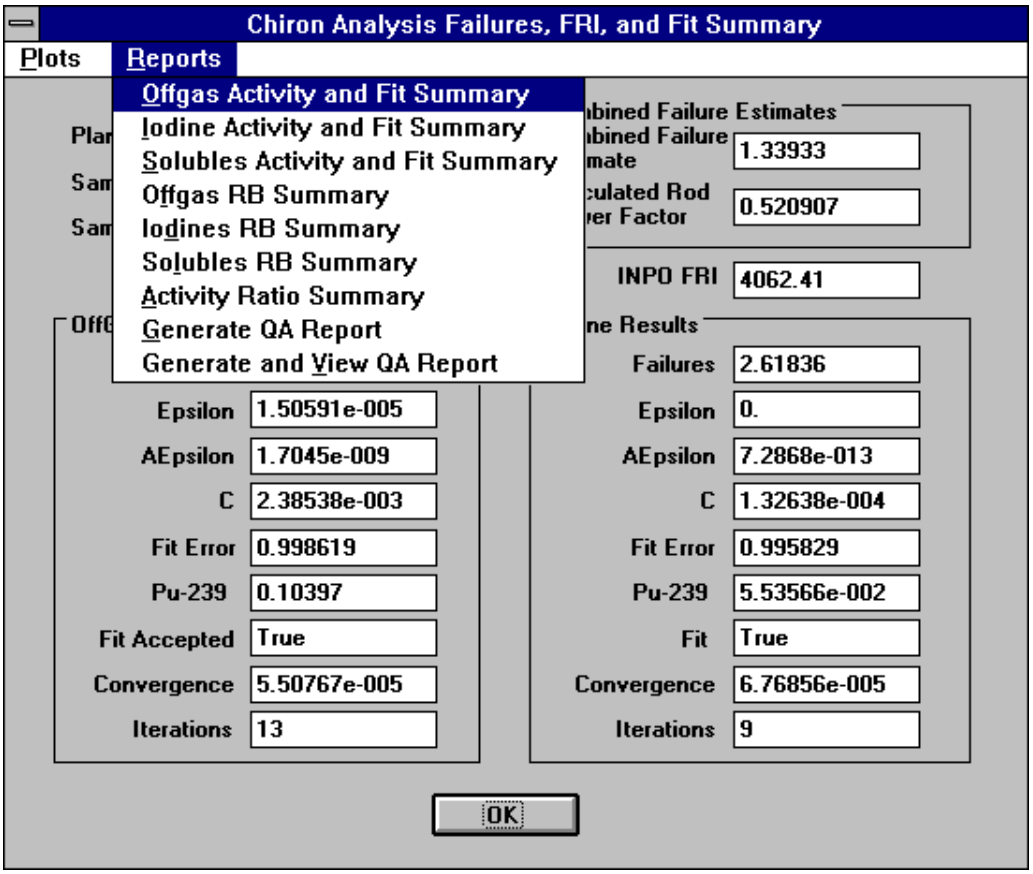

Figure 2-20
List of Available Reports

Step 9: Performing Batch Analysis and Generating ASCII Dump File

The program goes back to the Samples Select box. Click on "Analyze Batch". You will be asked to enter an ASCII Dump Filename. Click "OK" to accept the default filename, "Chirond". The three samples selected by x-marks will be analyzed. A box appears as shown in Figure 2-21 showing the status of the batch analysis including the record being analyzed and the total number that are marked for analysis. The box also contains a cancel button to stop the analysis.

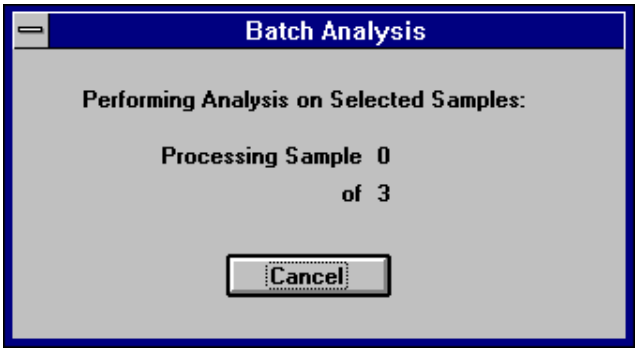

Figure 2-21
Dialog Box for Performing Batch Analysis

Step 10: Creating Trend Plots

After analyzing the selected samples in Step 9 above, the program opens a dialog box for trend plot selection as shown in Figure 2-22. This dialog box contains two list boxes, one for the first y-axis, and one for the second y-axis of a dual y-axis trend plot. Click on the arrow to the right of each box to view the list of choices. Note that the two lists are identical, but default selections are different. A check-box is available to select single y-axis plotting, if desired. It is also possible to cancel trend-plot selection by clicking the "Cancel" button.

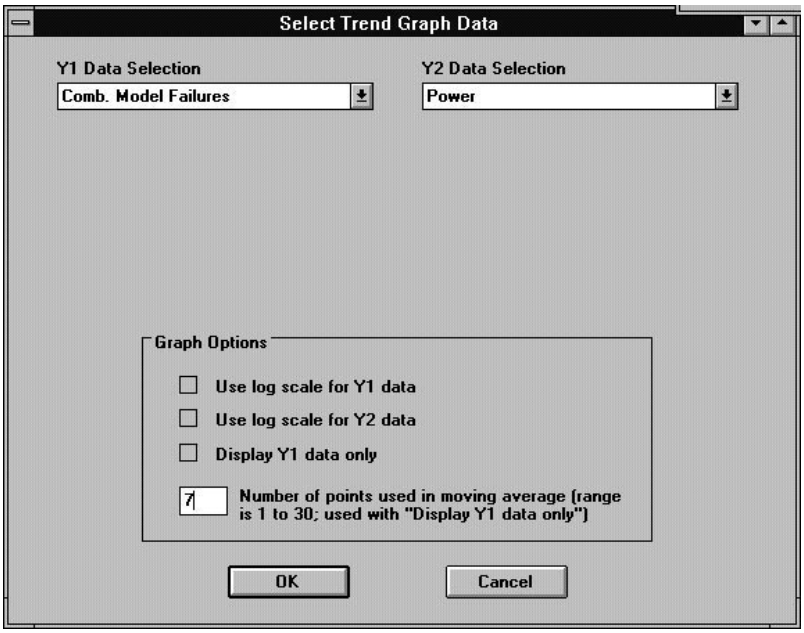
Select Trend Graph Data
Y1 Data Selection
Comb. Model Failures
Y2 Data Selection
Power
Graph Options
Use log scale for Y1 data
Use log scale for Y2 data
Display Y1 data only
7
Number of points used in moving average (range is 1 to 30; used with "Display Y1 data only")
OK
Cancel

Figure 2-22
Dialog Box for Trend Plot Selection

At this point, cancel the trend plot selection by clicking the "Cancel" button (the default selection is effective). The program now opens the Trend Plotting Anchor box (see Figure 2-23). This box offers three choices: "DISPLAY Trend Graph", "SELECT Graph Items" and "Cancel". Choose "Cancel". Our present batch sample analysis is too small to produce a meaningful trend plot. We will increase the number of samples so we can produce a more useful trend plot.

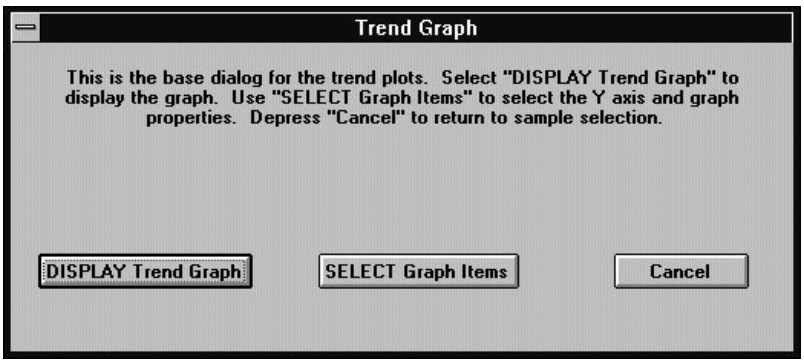
Trend Graph
This is the base dialog for the trend plots. Select "DISPLAY Trend Graph" to display the graph. Use "SELECT Graph Items" to select the Y axis and graph properties. Depress "Cancel" to return to sample selection.
DISPLAY Trend Graph
SELECT Graph Items
Cancel

Figure 2-23
Anchor Box for Trend Plotting Control

After selecting "Cancel", the program goes back to the Samples Select dialog box (see Figure 2-18). Deselect the previously selected samples by clicking the "Clear All Selections" button. To get a larger batch selection more suitable for trend-plotting, click on the "Time-Select Batch" button. A dialog box opens to permit the selection of a time period for batch-analysis/trend-plotting (see Figure 2-24).

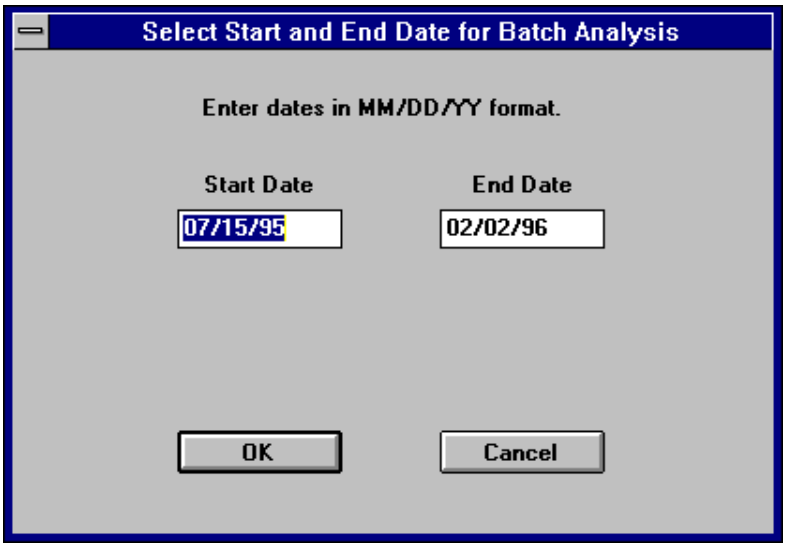

Figure 2-24
Time-Select Dialog Box

Enter start date 07/25/95 and end date 08/03/95. Click OK. You are returned to the Sample Select dialog box. This will select (x-mark) all 36 samples within this time period. To "thin" the selection, deselect the following samples by highlighting individually and clicking on the "Toggle Status" button: 7/28/95 at time 23:10:00, 7/29/95 at 21:02:00, 7/30/95 at 20:18:00, 7/31/95 at 21:10:00, 8/01/95 at 21:05:00, and 8/02/95 at 20:55:00. Click "Analyze Batch" again. An ASCII dump filename dialog box appears. Then you will see the box showing the status of the analysis of the samples (similar to Figure 2-21). Next you will see the trend plot selection screen (Figure 2-22) again.

By default, "Comb. Model Failures" is selected for the Y1 data and "Power" is selected for the Y2 data. The dialog box also allows the selection of logarithmic/linear scales, as desired, as well as a moving average range (number of samples over which to average). The moving average can be applied to all functions shown in single y-axis plots. Keep the default options, i.e., linear scales and 7 for running average range. Now press OK. The program returns to the Trend Plot Anchor box. Select "DISPLAY Trend Graph" to display the selected trend plot. The plot shown in Figure 2-25 appears.

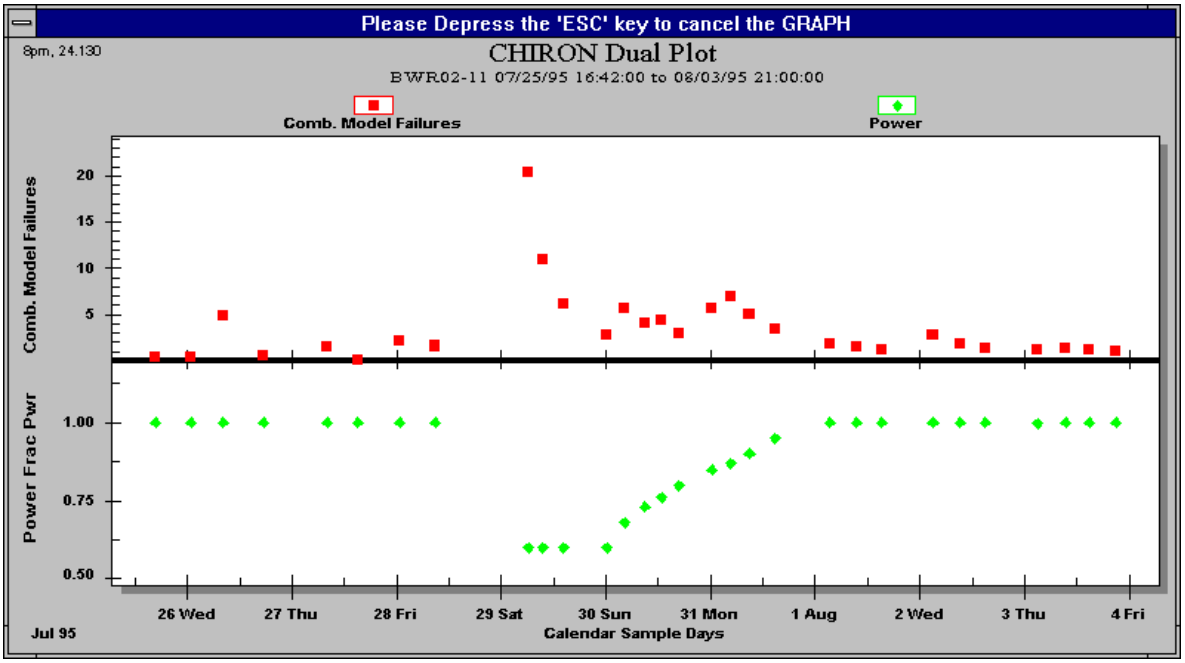

Figure 2-25
Trend Plot of Batch Sample Analysis

Step 11: Customizing Trend Plots

The trend plot appears with the default options for grid-lines, point markers, lines/no-lines, etc. Position your mouse anywhere on the graph. Click the right

mouse button to bring up the menu for customizing your plot. There are several options available including such things as fonts, grid lines, labels, etc.. Table 2-1 below describes these options.

Table 2-1
Table of Plot Options

List of Options	Description of Function
Viewing Style	Choose the way you want your plot displayed.
Color	Plot will be displayed in color.
Monochrome	Plot will be displayed in monochrome.
Monochrome + Symbols	Plot will be displayed in monchrome + symbols.
Font Size	Choose the font size you want used in your plot headings and data.
Large	Use large size fonts.
Medium	Use medium size fonts.
Small	Use small size fonts.
Numeric Precision	Choose the numeric precision to be used in plotting the data points.
No Decimals	Integer numbers used when plotting data points.
1 Decimal	Numbers truncated to one decimal point in plots.
2 Decimals	Numbers truncated to two decimal points in plots.
3 Decimals	Numbers truncated to three decimal points in plots.
Data Shadows	Places a shadow on each data point to increase visibility.
Grid Lines	Show grid lines on plot display.
Both Y and X Axis	Show grid lines on both axes.
Y Axis	Show grid lines on the Y Axis only.
X Axis	Show grid lines on the X Axis only.
No Grid	Do not show grid lines on the plot display.
Grid in Front	Grid lines appear in front of data points. If a data point falls directly on a grid line, the data point is obscured.

List of Options	Description of Function
Include Data Labels	Unique identifying labels are placed on each data point. Some plots have data labels designed specifically for that plot, while others will show default numeric, sequential data labels.
Mark Data Points	Put dots to mark the data points on the plot. By default this option is selected.
Show Annotations	Annotations have been set for certain plots. If annotations are set, they will appear when this is selected. The user cannot make customized annotations. By default this option is selected.
Undo Zoom	Display the plot in normal scale.
Maximize	Maximize the size of the plot display.
Customization Dialog General Plot Style Subsets Fonts Color	You can edit the various style settings to customize your plot display. Many of the items found in this option are available as individual options elsewhere in this menu, but are repeated here on one menu to allow you to customize everything at once. There are many plot styles to choose from such as bar, area, line, points, etc. See the Help option for assistance on using all of these options.
Export Dialog Export: Metafile Bitmap Embedded Object Text/Data Only Export To: Clipboard File Printer	Export the plot. Determine the file type for exporting, the destination for the export and the object size for exporting. Export the plot in metafile format. Export the plot in bitmap format. Export the plot in embedded object format. Export the plot in text/data file format. Export the plot to the clipboard. Export the plot to a file. Export the plot to a printer. Choose the size to print, i.e., full-size or a specified size.
Help	Displays help screen containing a indexed list of help categories for the options found on this menu. Find the option you need help with and a detailed explanation will be provided on the use of the option.

To see an example of a couple of these features, start by choosing "Grid Lines" from the menu. This brings up a submenu. Click on "Both Y and X Axis". The plot reappears with gridlines. Now, click the right mouse button again and choose the "Customization Dialog". A dialog box appears that has five sheets: General, Plot Style, Subsets, Font, and Color. Choose the sheet named "Plot Style". You will see the screen shown in Figure 2-26.

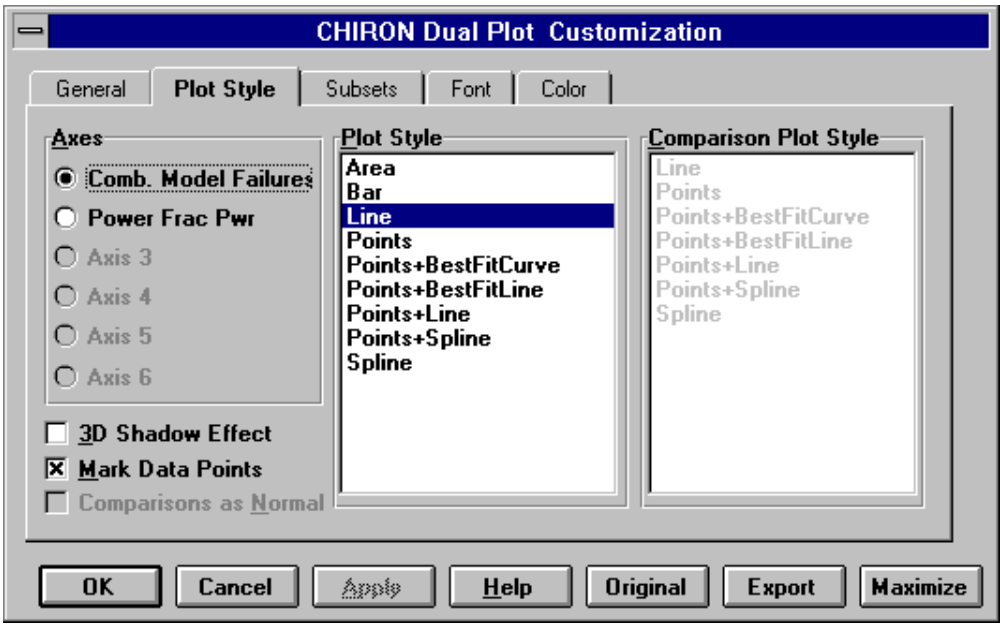

Figure 2-26
Trending Graph Customization Dialog Box

From that sheet, under "Axes", choose the y-axis labeled "Comb. Model Failures". Under "Plot Style" select "Line". Next, select another choice under "Axes", "Power Frac Pwr". Select "Line" for Plot Style again. Accept the changes by clicking "Apply". To show your action has been applied, the "apply" button is grayed or disabled now. Then click OK to get back to the plot. The plot has now changed its appearance as shown in Figure 2-27. Experiment some more to become familiar with the various options for customizing your plots.

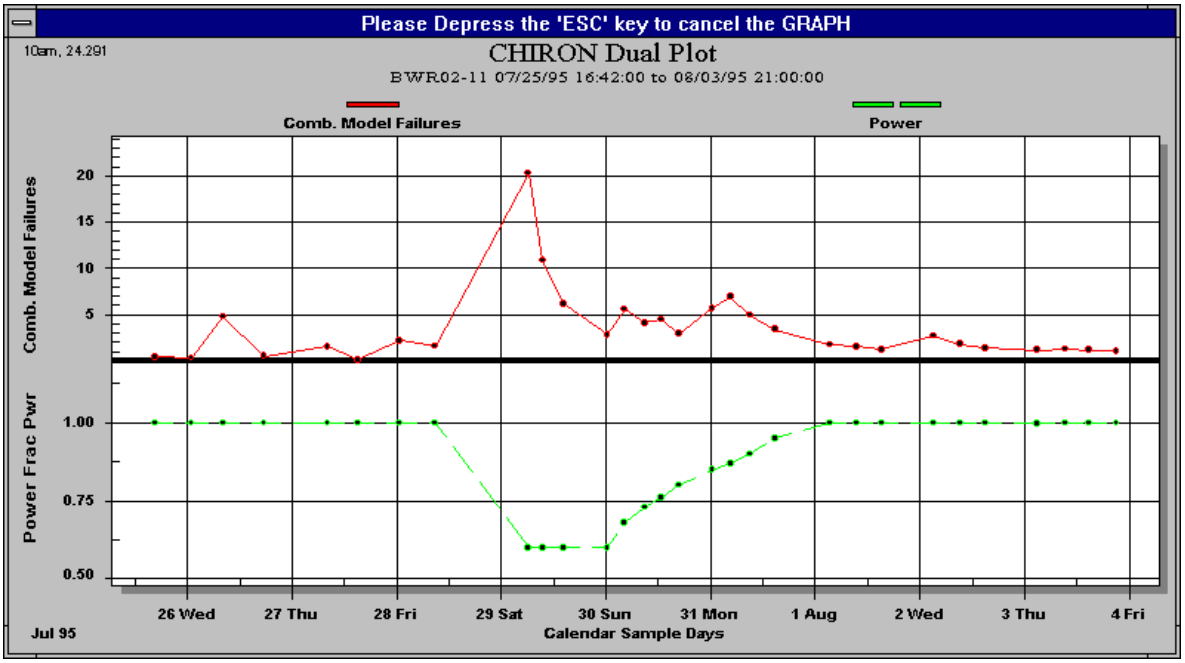

Figure 2-27
Sample Trend Plot

Two additional features are found in the trend plots and are accessed with the mouse button. As you move the mouse button on the plot note there is a time and number shown on the upper left corner of the plot. As you move the mouse, the number changes. This number identifies the coordinates of the mouse cursor within the graph area. If you leave the graph area, the number disappears. Also note that when the mouse is directly on a data point on the graph, a tiny hand appears so you know you are on a data point and can identify the coordinates shown in the upper left corner with that point. Put your mouse directly on a data point and see the tiny hand symbol.

A second feature that is useful when working with plots, is the zoom feature. To zoom in (magnify) on a particular portion of the plot, click and hold down the mouse button while moving the mouse over the area you wish to enlarge. A box will form on the screen indicating the area you are encompassing in your zoom. When you release the mouse button you see part of the plot in an enlarged state. When you wish to return to the normal plot state, click on the right mouse button and select the “undo zoom” option.

Step 12: Printing

Finally, as a final exercise in trend plots, try printing to an available WINDOWS printer by performing the following: from the right mouse button menu, choose the "Export Dialog". From the Export Dialog choose "MetaFile" as the type of file you are exporting; "Printer" as the export designation; and "Full Page" as object size. Click "Print". A printer configuration box appears. Verify the printer you are printing to, the paper selection, etc. Click OK. If an appropriate printer configuration exists under WINDOWS, the plot will be printed.

Step 13: Exiting from CHIRON

Now, close the trend plot by pressing the "Esc" key on the keyboard. The anchor box reappears. Press "Cancel" to quit trend plotting. On "Cancel", the program goes back to the Samples Select dialog box (Figure 2-18). Close this box. The program goes back to the main window. Select "Exit" under the "Data" menu to exit from CHIRON.

3

DATA ENTRY

This section provides detailed information on the various methods and formats used to enter new data and edit existing data in the CHIRON 3.0 database. Two methods of entering new data are supported in CHIRON: screen input and file input. All data entered into the CHIRON 3.0 database must conform to the database structure and data units. Data units, data ranges and default values (if available) for each data type are provided in this section. CHIRON allows the user to input the numerical values in any numerical format, i.e., decimal, integer, or exponential.

A data range checking procedure in CHIRON 3.0 performs unit conversions where appropriate. It also performs certain checks on input data to minimize the risk of serious numerical problems due to accidentally entered input values that are dramatically out of range. Tables 3-1 and 3-2 list the acceptable CHIRON data ranges.

3.1 Data Units (Cardinal Units)

When data is input to CHIRON the user must be sure to use the data units that are supported by the CHIRON program. Units are defined in the CHIRON database for each data entry field. A set of reference units, referred to as the "Cardinal Units" are used internally in CHIRON, as well as for all on-screen output. In addition, the user selects a set of input units from a pre-defined list of choices shown in list-boxes on the sample data units screen.

To check the data units currently in effect, perform the following:

- From the main window, select "Data"
- Click on "New"
- Select "Edit Units" from the New Data dialog box. The Sample Data Units dialog box appears and lists the Cardinal Units for each sample data input item (see Figure 3-1).

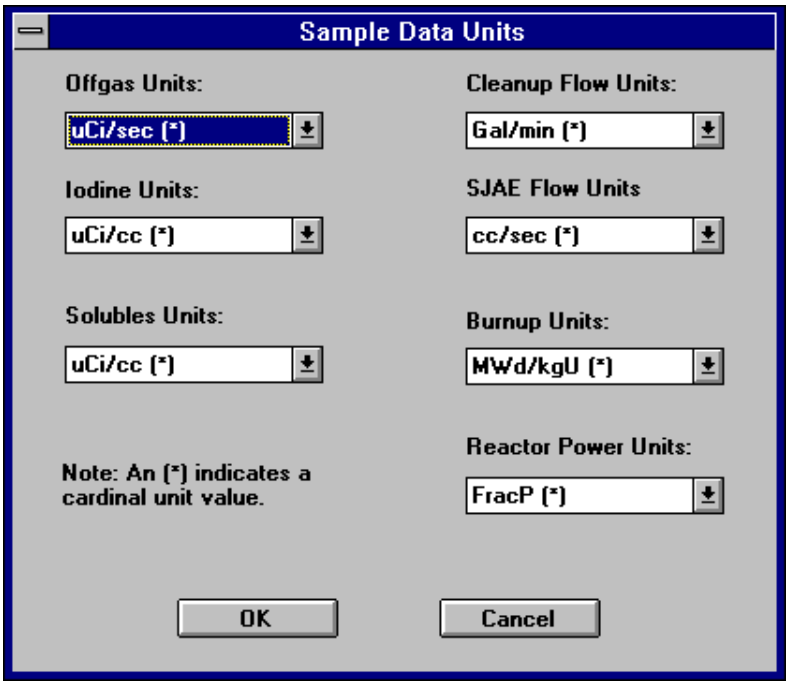

Figure 3-1
Edit Units – Sample Data Units

The asterisks in parentheses indicate that these are cardinal units that CHIRON uses internally. CHIRON converts from the selected units to the appropriate cardinal units, using built-in conversion factors.

Note: CHIRON initially has the cardinal units set as the selected units. As changes are made to the input units, the selections are saved in the database. Therefore, the latest choice made will be in force until changed by the user.

3.2 Entering Plant Design and Cycle Operational Data

Prior to entry of new sample data, the user needs to check that the Plant-Cycle ID exists in the database. This is done by clicking on "Options" from the Main Window, followed by "Plant Config", then selecting "Edit Existing Plant". This opens the Edit Plant-Cycle Configuration Box as shown in Figure 3-2.

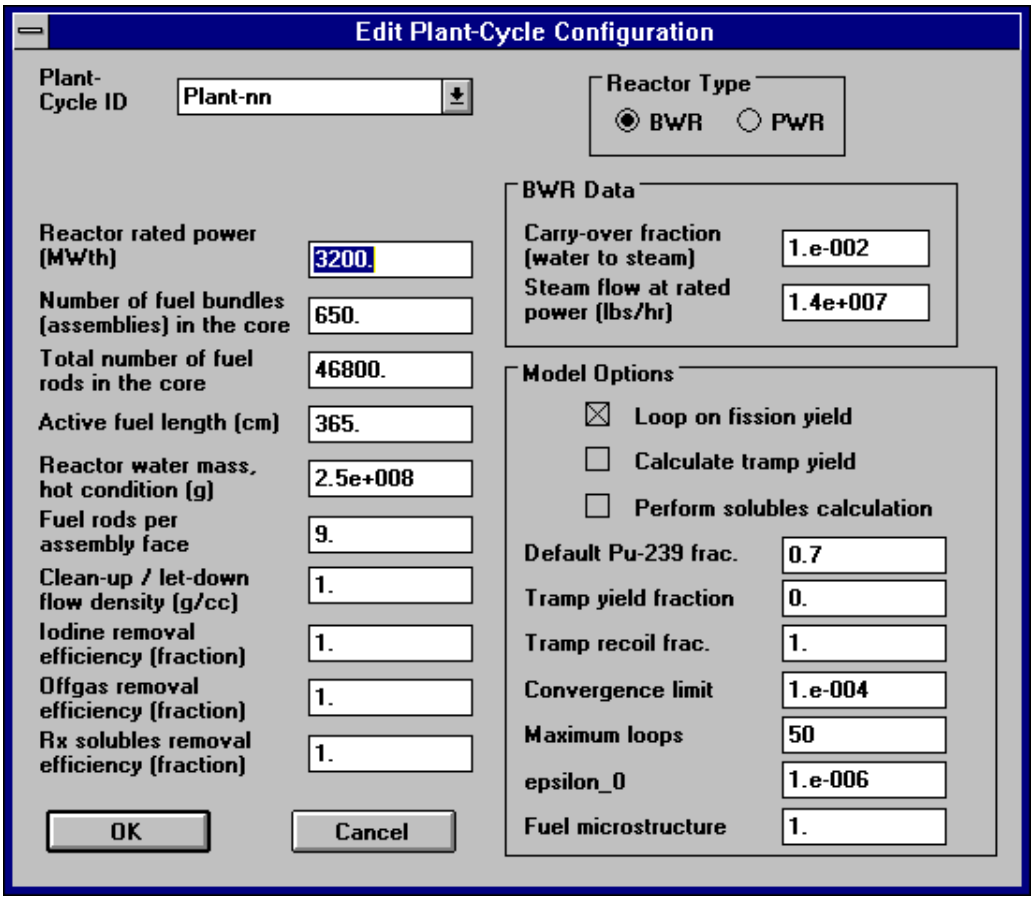

Figure 3-2
Edit Plant Cycle Configuration Box

Remember, CHIRON always opens the CHIRON DB database initially. In Section 2.3 when you installed CHIRON you set up CHIRON DB with the Chiron1.mdb database file. The plant cycles contained in Chiron1.mdb appear in the Plant Cycle ID list in Figure 3-2.

The Plant-Cycle IDs list box shows all Plant Cycle IDs entered into the database. If the desired plant-cycle already exists, then its configuration data may be loaded by selecting the plant-cycle ID from the list-box. The configuration may be edited and then saved by clicking OK.

If the desired plant-cycle is *not* found in the current list, then the user must add a new Plant Cycle ID. To add a new Plant Cycle ID, click "Cancel" to return to the Main Window. From the Main Window, select "Options", then choose "Plant Configuration", then "Add New Plant" from the drop-down menu. This will open the Add Plant-Cycle Configuration screen (see Figure 3-3), allowing you to enter the configuration of a new plant-cycle.

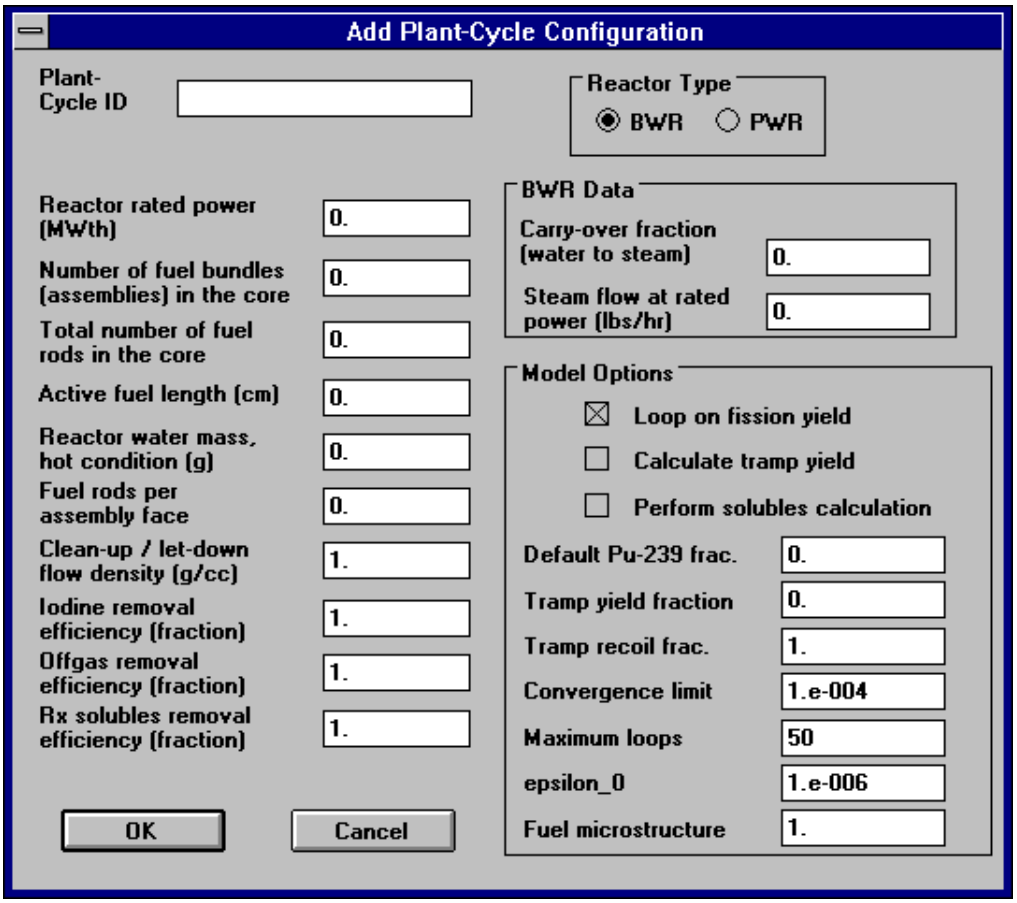

Figure 3-3
Add Plant-Cycle Configuration Box

Add the data in each box starting with Reactor rated power. Click on the data field you are entering and type in the appropriate data. Be sure to enter the data in the units noted in parentheses next to the item, i.e., Reactor rated power must be entered in MWth units. Table 3-1 provides detail on the Plant Cycle Configuration data entries, including the acceptable data ranges and any default values used in the program. **Note: Unless otherwise indicated, data values may be entered in any numeric format, i.e., decimal, integer or exponential. The program will convert the entries to the Cardinal Units used internally by the program.**

When you click OK, the program performs a range check on each value. If all values are acceptable, then the data is saved to the database and you are returned to the CHIRON main window. If you click on the "Cancel" button, then the data is not saved and you are returned to the CHIRON main window.

If any data item is out of range, a message will appear showing a list of all items that are out of range. On clicking OK, the user is returned to the dialog box to fix the problem(s). No data will be entered into the database until all the required ranges have been satisfied.

Table 3-1.
Plant Cycle Configuration Data Entry Options

Plant Cycle Config. Data	Data Range	Description
Reactor rated power	0<RatPow≤10000 in MWth	The reactor rated power.
No. of fuel assemblies in the core	0<NFAss≤2000 in any numeric format	The number of fuel assemblies in the reactor core.
Total number of fuel rods in the core	n^2* NFAss * 0.5 ≤Nrods≤n^2* NFAss * 2	The total number of fuel rods in the reactor core.
Active fuel length	0<Act FuelL ≤1000 in cm	The length of the active fuel.
Reactor water mass, hot condition	$1.0x10^5$≤WM≤ $1.0x10^{10}$ in grams	The water mass in the reactor at hot condition.
Fuel rods per assembly face	For BWRs: 6≤n≤12 For PWRs:14≤n≤20	The number of fuel rods per assembly face.

Plant Cycle Config. Data	Data Range	Description
Clean-up/let down flow density	0.5≤CUDens≤2.0 in g/cc	The cleanup or letdown flow density.
Iodine removal efficiency	0<IEff≤1 in fraction	The Iodine removal efficiency (normally assumed to be unity) is used to compute the isotopic loss term caused by the clean-up/letdown system. This value represents the efficiency of the removal system (e.g. the ion-exchange beds). This value may vary slightly over time, but should remain very close to 1.0 representing 100% removal efficiency.
Offgas removal efficiency	0<OGEff≤1 in fraction	The Offgas removal efficiency (normally assumed to be unity) is used to compute the isotopic loss term caused by the clean-up/letdown system. This value represents the offgas removal efficiency of the letdown flow system. This value may vary slightly over time, but should remain very close to 1.0 representing 100% removal efficiency.
Rx solubles removal efficiency	0<RxEff≤1 in fraction	The Rx solubles removal efficiency (normally assumed to be unity) is used to compute the isotopic loss term caused by the clean-up/letdown system. This value represents the efficiency of the removal system (e.g. the ion-exchange beds). This value may vary slightly over time, but should remain very close to 1.0 representing 100% removal efficiency.

Plant Cycle Config. Data	Data Range	Description
Loop on fission yield		If this option is selected, CHIRON performs an iteration on the Pu^{239} fission yield ratio for the failed fuel. CHIRON searches for the fission yield that provides the best overall statistical fit. If the option is not selected, the user must supply a value for the yield ratio (see Default Pu^{239} frac).
Calculate tramp yield		If this option is selected, CHIRON sets the Pu^{239} fission yield ratio for the tramp to be equal to the value for the failed fuel. If the option is not selected, the user must supply a value for the yield ratio (see Tramp Yield frac).
Perform solubles calculation		If this option is selected, CHIRON performs a least squares fit of up to 15 "solubles" activities. Np239 is not included, since it is not a fission product.
Default Pu^{239} frac.	$0 \leq PuFrac \leq 1.0$	If the "Loop on fission yield" option is not selected, CHIRON will use the value specified here for the Pu^{239} fission yield ratio for the failed fuel.
Tramp yield fraction		If the "Calculate tramp yield" option is not selected, CHIRON will use the value specified here for the Pu^{239} fission yield ratio for the tramp.
Tramp recoil frac.	$0 < TrRecFrac \leq 1$	The value specified here is the fraction of the tramp for which the fission products generated are directly released into the coolant. For normal tramp levels, 1.0 should be used. For very high tramp levels, a value less than unity may be specified.

Plant Cycle Config. Data	Data Range	Description
Convergence limit	$1.0x10^{-8} \leq Crit \leq 1$	The value specified here is the maximum error in the coefficients allowed for a valid solution.
Maximum loops	$0 < Nloops \leq 10000$	The value specified here is the maximum number of iteration loops permitted for the least squares fitting routine.
epsilon_0	$10^{-8} \leq epsilon\_0 \leq 10^{-2}$	The value specified here is used as a default epsilon in the Combined Failure Model, when a "Three-Coefficient Fit" has resulted from the least squares fitting routine.
Fuel microstructure	$0.1 \leq Fmic \leq 100$	The value specified here characterizes the fission product diffusivity of the failed fuel. For US-made fuel the recommended value is unity. For certain foreign made fuel types, especially fuel made by the AUC process, the value may be higher.

3.3 Entering New Sample Data Input

CHIRON supports two methods for entering new sample data: 1) the data entry dialog box or 2) the file-read option. Before loading any sample data it is important to first enter the Plant Cycle ID using the plant cycle configuration screen. This procedure is described in Section 3.1 above. Entry of new sample data into CHIRON starts from the CHIRON main window. Select "Data" and then "New" from the drop-down menu. This brings up the New Data dialog box as shown in Figure 3-4.

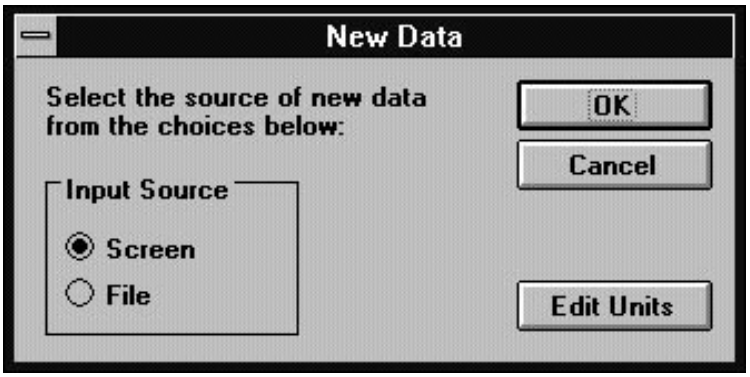

Figure 3-4
New Data Dialog Box

The input methods available for entering new sample data are "Screen" and "File", selectable by the radio-buttons. "Screen" is intended for single sample input, "File" for multiple sample (batch) input. The following subsections deal with each of these input methods separately.

3.3.1 Single Sample Activity Data Input

Before entering sample data, verify the data units that are currently in effect. To do this, click on "Edit Units". The Sample Data Units dialog box appears (see Figure 3-5).

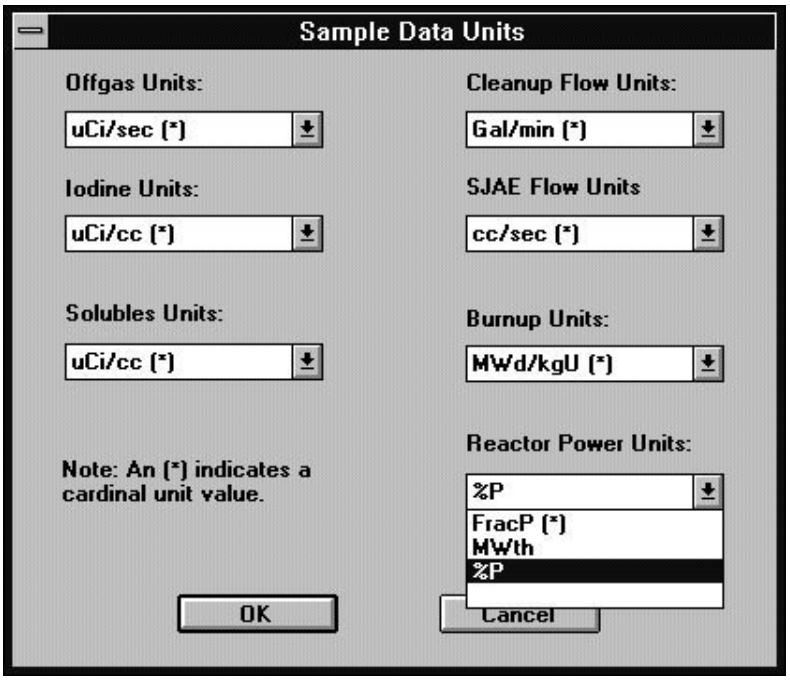

Figure 3-5
Sample Data Units Dialog Box

If the input units shown in the list-boxes of the Sample Data Units dialog box are the ones desired then the box is closed by clicking "Cancel". Otherwise, alternate units may be selected by holding down on the arrow next to each data unit. In the case shown in Figure 3-5, the list-box for Reactor Power Units has been opened. The available choices are shown in the scroll list and include: "FracP" for fractional power (normally between 0 and 1), "%P" for percent power (normally between 0 and 100), and "MWth" for absolute power in MWth. The asterisks in parentheses indicate that these are cardinal units that CHIRON uses internally. CHIRON converts from the selected units to the appropriate cardinal units, using built-in conversion factors.

If changes are made to any of the items in the Sample Data Units dialog box, click OK to accept the changes. Choose "Cancel" to go back to the New Data screen without accepting any changes.

Now you are ready to enter data. To enter Single Sample Input, click "Screen" from the New Data dialog box, then OK. The Add Sample dialog box appears as shown in Figure 3-6.

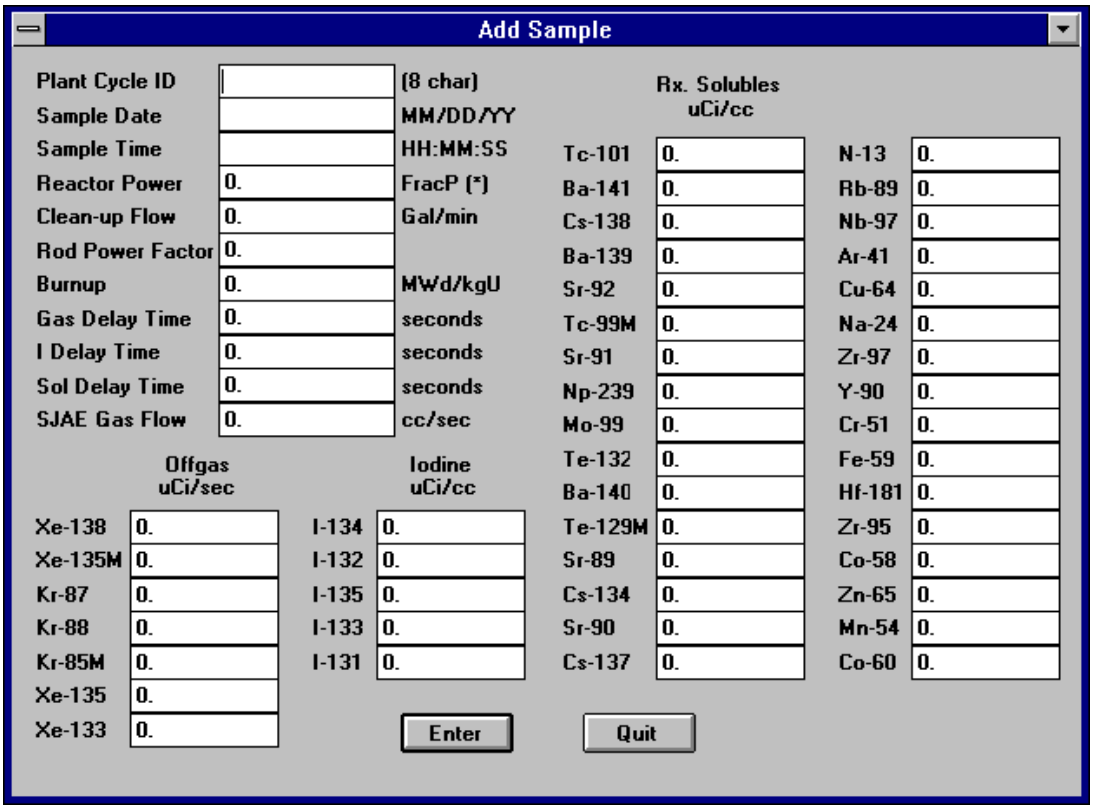

Figure 3-6
Add Sample Dialog Box

Input units are shown by each value to remind the user of the current settings. Table 3-2 provides definitions for the sample data entry fields entered on this screen.

Table 3-2.
Sample Data Input Units

Sample Data Input	Data Range	Description
Plant Cycle ID	xxxxx-nn	The Plant Cycle ID must coincide with one available in the database. Its format is a 5-character text-string (Plant Name), followed by a hyphen ("-"), followed by a single or double digit number (Cycle Number). The plant name is case sensitive. Do not use a leading zero in a single digit cycle number.
Sample Date	mm/dd/yy	The sample date entered in the form MM/DD/YY.
Sample Time	hh:mm:ss	The sample time entered in the form HH:MM:SS.
Reactor Power	0≤RxPow≤10 in FracP	The *current reactor power* (as opposed to rated power).
Clean-up Flow	0< ClFlow≤10000 in gal/min	The cleanup or letdown flow rate (required for conversion of μCi/ml to μCi/sec).
Rod Power Factor	0<RPF≤10	The ratio of the linear heat-rating of the failed fuel, if any, to the average linear heat rating of the entire core, at the *current reactor power* level. For File Read input, occurrences of RPF = 0 will be replaced by the default value 1.08.
Burnup	0≤BU≤1000 in MWd/kgU	An estimate of the burnup of the failed fuel.
Gas Delay Time	-5000≤DelTime ≤50000 in seconds	Any delay that may occur between activity release for offgas isotopes at the fuel breach, and sample capture. The delay due to coolant circulation time is usually negligible.

Sample Data Input	Data Range	Description
I Delay Time	-5000≤DelTime ≤50000 in seconds	Applies to the iodines, and is otherwise defined as above for the offgas isotopes.
Sol Delay Time	-5000≤DelTime ≤50000 in seconds	Applies to the reactor solubles, and is otherwise defined as above for the offgas isotopes.
SJAE (Steam Jet Air Ejector) Gas Flow	For BWRs: 500≤SJAEFlow ≤50000 in cc/sec For PWRs: SJAEFlow=0	The flow rate of the steam in the bypass line that drives the evacuation of non-condensable gases from the condenser, by means of a jet nozzle. The flow rate is used for BWRs as a conversion factor between measured activity in μCi/cc and release rate activity in μCi/sec.
Offgas Activities	volumetric units: 0≤Abs{VolOGAct} ≤1.e6 in μCi/cc release-rate units: 0≤Abs{RrOGAct} ≤5.e8 in μCi/sec	Measured activity of the offgas or noble gas isotopes. A negative value for an isotopic activity has the effect of omitting the activity value from the R/B fit and subsequent fuel failure evaluations, although the measurement value is retained in the CHIRON database for reference purposes.
Iodine Activities	volumetric units: 0≤Abs{VolIOAct} ≤1.e6 in μCi/cc release-rate units: 0≤Abs{RrIOAct} ≤5.e8 in μCi/sec	Measured activity of the iodine isotopes. A negative value for an isotopic activity has the effect of omitting the activity value from the R/B fit and subsequent fuel failure evaluations, although the measurement value is retained in the CHIRON database for reference purposes.
Rx Solubles Activities	volumetric units: 0≤VolSolAct≤1.e6 in μCi/cc release-rate units: 0≤RrSolAct≤5.e8 in μCi/sec	Measured activity of the selected reactor soluble isotopes. Reactor solubles cannot be included in R/B fit and, therefore, are always non-negative values.

Click on each data entry field and type in your data. When all data has been entered into the screen, clicking on "Enter" at the bottom of the screen will save the data to the database. The user will then be asked if he wants to add another sample.

For individual sample input, the range checking is performed in the "Add Sample" screen and the "Edit Sample" screen. The check is performed when the "Enter" or "OK" button is clicked, respectively. If any data item is out of range, a message will appear showing a list of all items that are out of range. On clicking OK, the user is returned to the dialog box to fix the problem(s). No data will be entered into the database until all the required ranges have been satisfied.

3.3.2 "File Read" (Batch Input) Sample Activity Data Input

Batch, or "File Read" input is selected by the radio button "File" in the New Data screen (see Figure 3-4).

Selecting "File" brings up the Input File Selection Screen, as shown in Figure 3-7. You select an input file and click OK. **Note: The files read must be formatted as described in Appendix B.** (If you wish to try this feature, an example input file, "dbcon09.txt", is provided on the CHIRON 3.0 distribution disk. Click on this file if desired.)

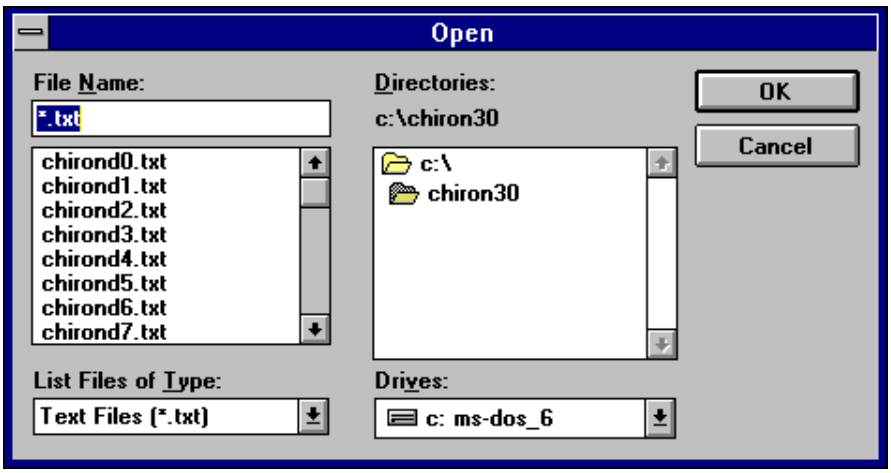

Figure 3-7
Input File Selection

The selected file is then read into CHIRON. A box appears that shows the line count as the file is being read. Note: The count indicates the total number of lines read from the file, including comment lines, i.e., not just the number of data samples. For "File Read" input, range checking is performed for each record

read, and any non-compliances are posted to the screen as they occur. In such cases, the user is advised of the problem and given the choice to either stop the read-in or to continue. None of the non-compliant records are transferred to the database.

If the file is read successfully, a list-box appears to show only the newly entered samples. This box is equivalent to the Samples Selection Box of Figure 2-17. Samples analysis may proceed from this box, in the manner previously explained in Section 2.5, Step 9 .To generate a list box containing all samples for the cycle, close this box and open the plant cycle again (see Section 2.5, Step 5).

Alternatively, batch input files may be created by organizing sample data in a spreadsheet, such as Microsoft Excel, according to the format shown in Appendix B, then saving the spreadsheet as a comma-separated text file using the "Save As" option from the spreadsheet file menu.

4

CHIRON OUTPUT

This section discusses the various output produced by CHIRON. With CHIRON the user can generate single-sample screen plots, various trending plots, screen reports and printed reports. Descriptions of the plot and report options are described in the subsections that follow. Illustrations of each type of plot and report are provided.

Plots and reports can be edited, copied to hard-disk as a bit-map file and/or printed to any printer installed under WINDOWS. By clicking on the right mouse button from anywhere inside a graph display, the user can access a menu containing numerous graphic display options that allow customization of the CHIRON plot. The user can modify the gridlines, font size, color, data labels, and more. Printing is controlled from the Export Dialog option, while editing is normally performed from the Customization Dialog option. A description of these plot options is provided in Section 2 in Table 2-1. By clicking on the "Help" option in the right mouse button menu, you can also access more information on these plot options.

4.1 Single-Sample Screen Plots

The list of available single-sample screen plots is shown below:

- Release to Birth (R/B) vs. Lambda for Offgas and Iodines
- R/B vs. Lambda for Solubles
- Cesium Ratio vs. Predicted Burnup
- F(Epsilon) vs. Epsilon
- C vs. Epsilon
- Failure Correlation Epsilon vs. A Epsilon
- Y versus X plot

These plots are accessed from the drop-down menu of the Analysis Summary screen (see Figure 2-19). The following subsections explain each plot in detail and provide illustrations of sample plots.

4.1.1 The R/B versus λ Plot, Offgas and Iodines

An example of the Release to Birth (R/B) vs. Lambda for offgas and iodines plot is shown in Figure 4-1. It contains a base-line curve (representing tramp) and a total activity curve (representing tramp plus failed fuel) for offgas, and a similar pair for iodines. The separation between the total and tramp activity, i.e., the rise of the R/B over the base-line, represents the failed fuel activity. Gridlines were added to this plot by using the menu option "Gridlines", available by clicking the right mouse button.

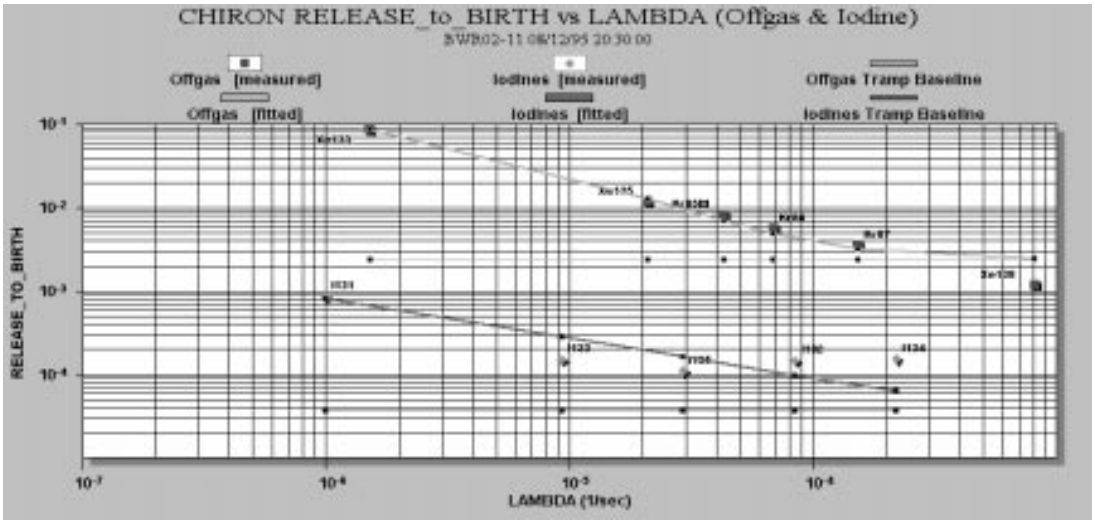

Figure 4-1
R/B versus λ Plot for Offgas and Iodines

For a typical sample, the offgas curves will tend to be higher than the iodines curves, due to the fact that iodines have more chemical affinity to other elements than do the noble gases. Thus, the behavior of the noble gases represent a close to ideal diffusion behavior, while the iodine activities may be attenuated because of reactions with other materials.

However, the separation between the offgas and iodines curves is temperature dependent, such that the separation tends to be smaller for higher temperature failed fuel.

4.1.2 R/B versus λ Plot, Solubles

An example of the R/B vs. Lambda for Solubles plot is shown in Figure 4-2. The original CHIRON solubles group consists of 15 fission products plus Np^{239}. Only the fission products are used in the R/B versus λ fitting routine. In the example, it is seen that the scatter of the points for the solubles group is such that no clear trend is indicated by the plot. This is fairly typical of the solubles analysis, and is of little overall value in fuel failure assessment. As a result, the solubles calculation is optional (selected in the Model Options section of the Plant Configuration dialog box illustrated in Figure 3-3).

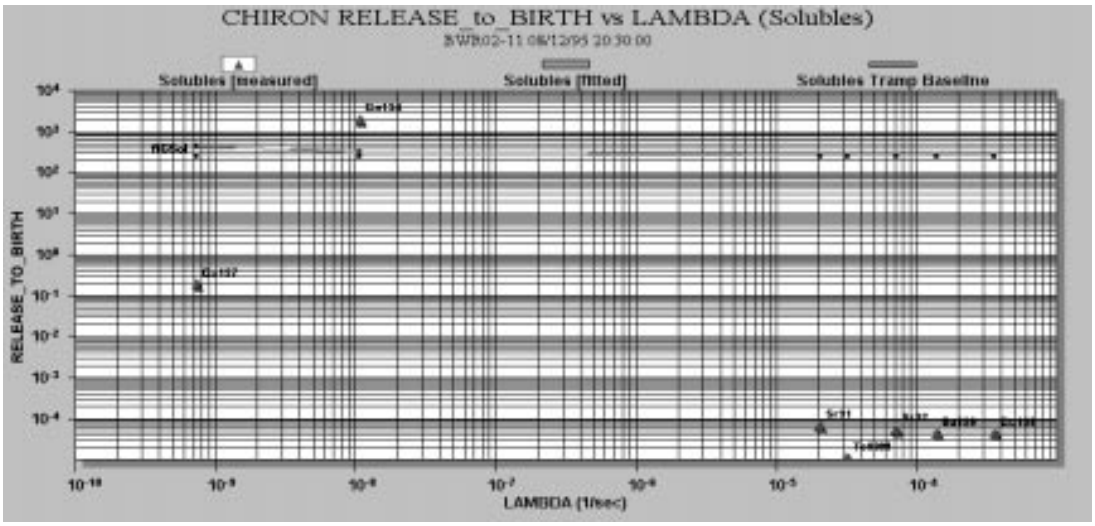

Figure 4-2
R/B versus λ Plot for Solubles

A significantly improved analysis can be obtained from the solubles, if the isotopes Cs^{134} and Cs^{137} are omitted. This can be done by bringing up the Sample Edit dialog box, then changing the sign of the Cs^{134} and Cs^{137} activities to negative, then clicking "OK" (see Figure 4-3, the negative values appear in red on the screen). This has the effect that these activities will be ignored in the least squares fit of the sample analysis. The result of the revised fit is shown in Figure 4-4.

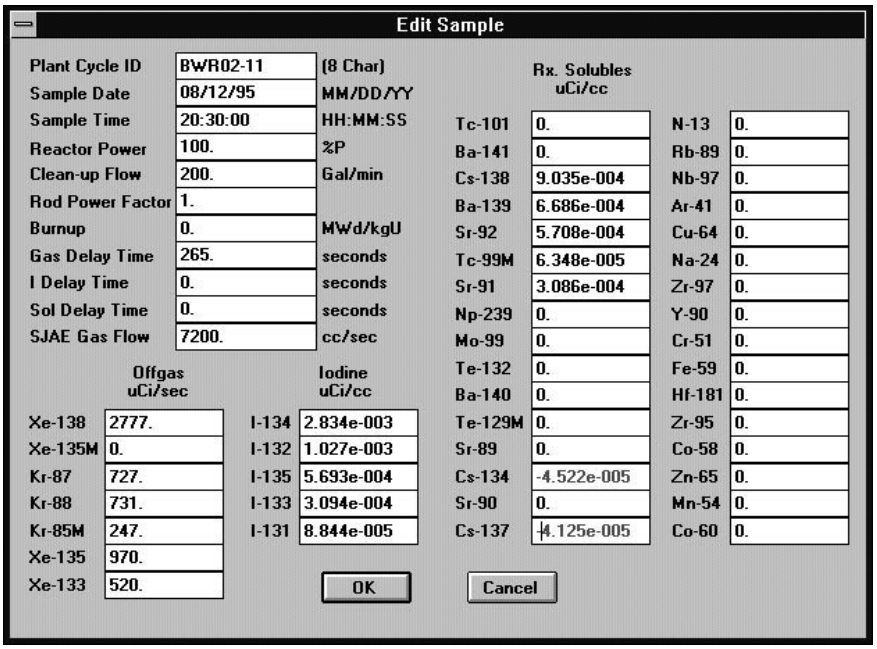

Figure 4-3
Sample Edit Screen Showing Deletion of Two Cs-Activities

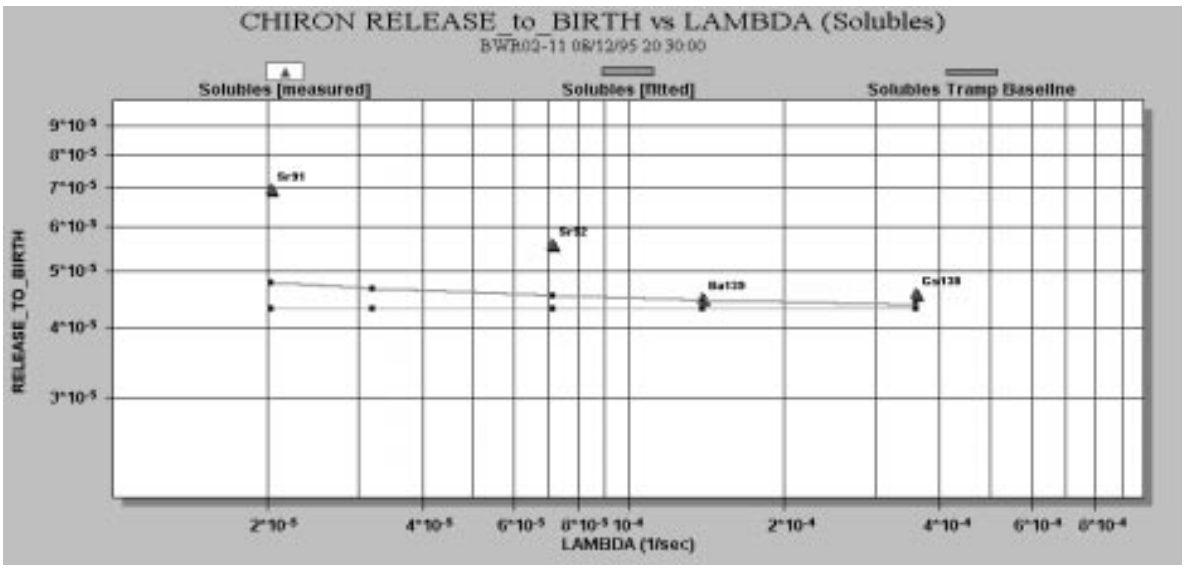

Figure 4-4
Revised R/B versus λ Plot for Solubles

It is envisaged that specific scenarios exist in which solubles analyses will prove very valuable, in particular when applied to certain subsets of solubles. Further

development is anticipated in this area. For the present, however, it is recommended that the solubles analysis be switched off for routine analyses. This is the default choice in the Add Plant Configuration dialog box, see Figure 3-3).

4.1.3 Cs-Ratio versus Predicted Burnup

The ratio of the two cesium activities Cs^{134} and Cs^{137} can be used to estimate the burnup of the failed fuel. When the Cs-ratio burnup plot is chosen, the dialog box shown in Figure 4-5 appears.

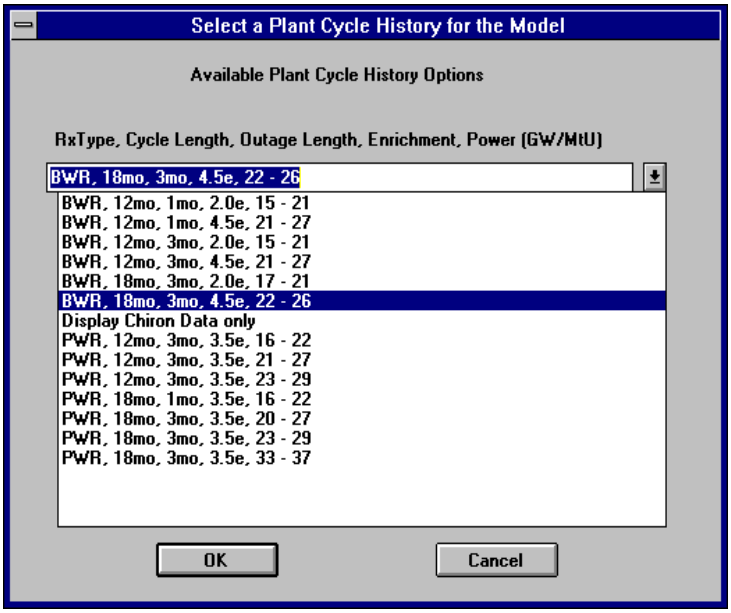
Select a Plant Cycle History for the Model
Available Plant Cycle History Options
RxType, Cycle Length, Outage Length, Enrichment, Power (GW/MtU)
BWR, 18mo, 3mo, 4.5e, 22 - 26
BWR, 12mo, 1mo, 2.0e, 15 - 21
BWR, 12mo, 1mo, 4.5e, 21 - 27
BWR, 12mo, 3mo, 2.0e, 15 - 21
BWR, 12mo, 3mo, 4.5e, 21 - 27
BWR, 18mo, 3mo, 2.0e, 17 - 21
BWR, 18mo, 3mo, 4.5e, 22 - 26
Display Chiron Data only
PWR, 12mo, 3mo, 3.5e, 16 - 22
PWR, 12mo, 3mo, 3.5e, 21 - 27
PWR, 12mo, 3mo, 3.5e, 23 - 29
PWR, 18mo, 1mo, 3.5e, 16 - 22
PWR, 18mo, 3mo, 3.5e, 20 - 27
PWR, 18mo, 3mo, 3.5e, 23 - 29
PWR, 18mo, 3mo, 3.5e, 33 - 37
OK
Cancel

Figure 4-5
Selection of Burnup Model for Cs-Ratio Burnup Prediction

The user may now select a "Plant Cycle History". The Plant Cycle History refers to a set of reference ORIGEN curves that are dependent on the plant type, cycle length, outage schedule, enrichment, and reactor power. These curves are available to compare the Cs ratio calculated by CHIRON to some reference cases. The user can select an option, click OK, and a plot similar to Figure 4-6 will be displayed. The CHIRON model is shown as the smooth curve, while the other curve represents the ORIGEN curve.

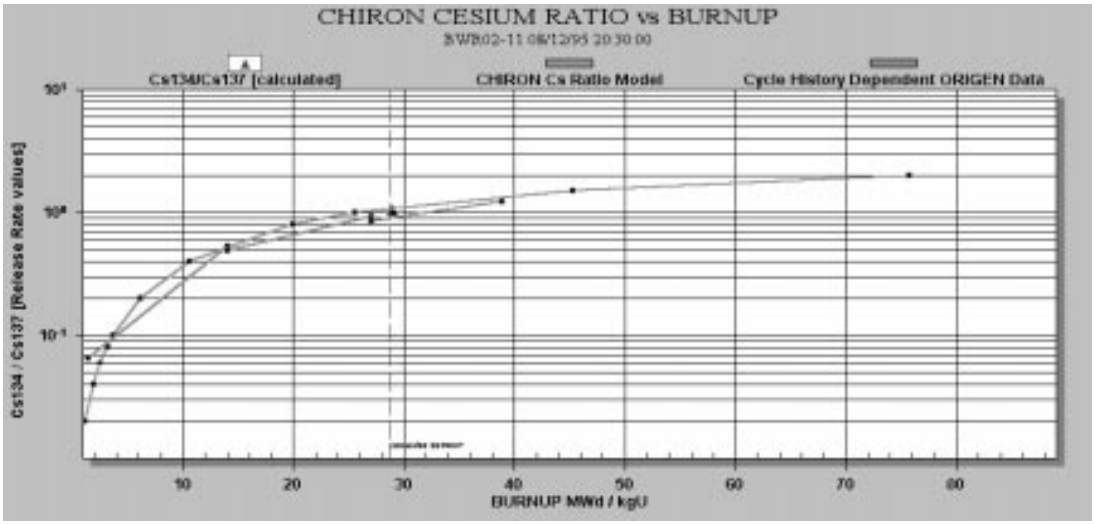
CHIRON CESIUM RATIO vs BURNUP
Cs134/Cs137 [calculated]
CHIRON Cs Ratio Model
Cycle History Dependent ORIGEN Data
Cs134 / Cs137 [Release Rate values]
BURNUP MWd / kgU

Figure 4-6
Cs-Ratio versus Predicted Burnup

4.1.4 f(ε) versus ε Plot

The f(ε) versus ε relationship is the fundamental expression in the CHIRON least-squares fitting routine (for the theoretical derivation, see Chapter 6). CHIRON seeks the root of this curve, which is then accepted as the calculated ε. f(ε) may have more than one root, as seen in Figure 47. If this is the case, the lower of the two values is the physically meaningful one.

The f(ε) versus ε relationship plot is included in CHIRON to allow the user to scrutinize sample analyses for their detailed numerical behavior. The plot includes three curves depicting the offgas, iodines and solubles analyses. The roots determined by CHIRON are marked on the plot for each isotopic group.

To study details of the plot, use the zoom feature. Zooming is accomplished by depressing the left mouse button at the upper left corner of the rectangle that defines the desired view, then dragging to the lower right corner and releasing. To get out of the zoomed view, select the menu item "Undo Zoom", available by clicking the right mouse button anywhere in the graph area.

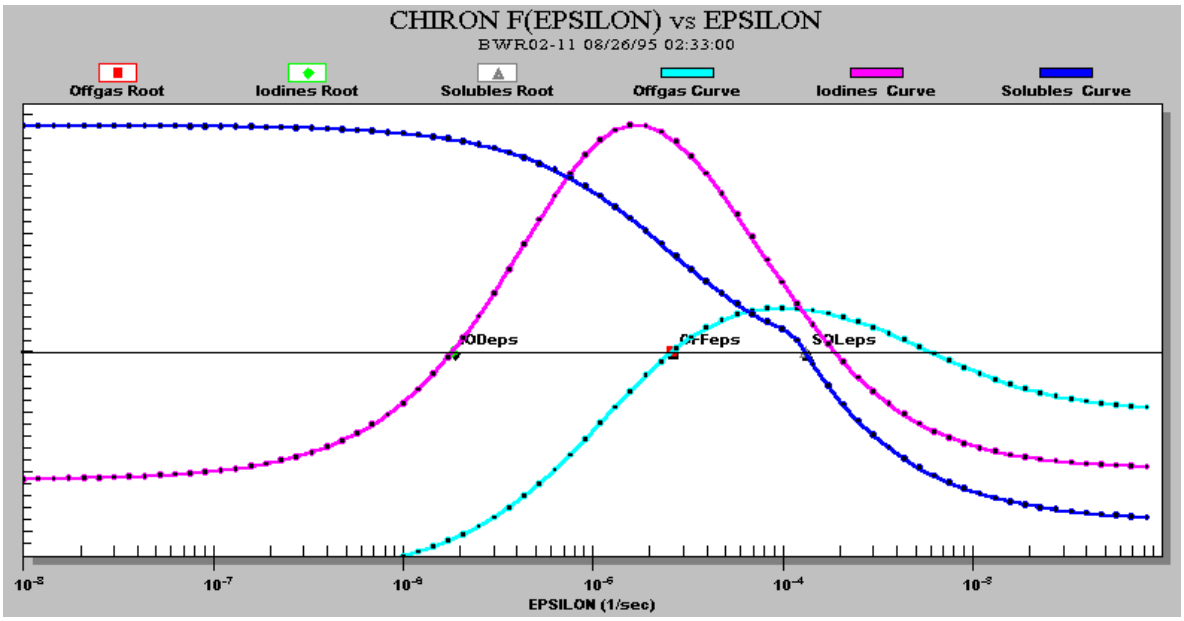

Figure 4-7
f(ε) versus ε Plot

4.1.5 C(ε) versus ε Plot

The C(ε) plot (Figure 4-8) is shown to support the understanding of the way CHIRON accepts or rejects a fit analysis. Normally, CHIRON calculates three coefficients: "ε", "Aε" and "C". Sometimes, however, the analysis defaults to providing only two coefficients. This happens for instance when the "C" coefficient turns out negative for the calculated ε. This would correspond to negative tramp (see Chapter 6), and is, therefore, not acceptable. Thus, CHIRON will discard the "three-coefficient fit" and instead present a "two-coefficient fit", based on recalculated values of C and Aε (see Chapter 6 for details).

The C(ε) plot enables the user to see how the coefficient C varies with epsilon. For an acceptable "three-coefficient fit", the C-value at the calculated epsilon, must be positive. The calculated epsilons are marked in the C-plot for each isotopic group. The plot will attempt to show C-coefficient curves for all three isotopic groups, if calculated. However, in some cases scaling may result in the disappearance of some curves from view. The zoom feature described earlier in this section can then be used to study the detail on the plot.

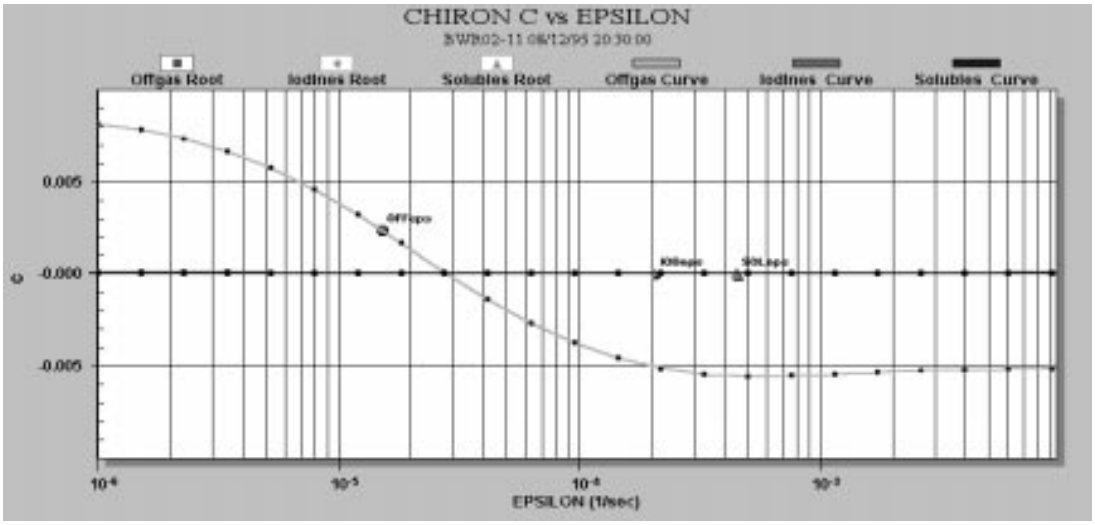

Figure 4-8
C(ε) versus ε Plot

4.1.6 Failure Correlation Plot

The correlation provided in CHIRON to estimate the number of failed fuel rods utilizes an empirical fit that relates the aε and ε coefficients to the number of fuel failures. The third coefficient, "C", is used to correct the nuclide activity for recoil release, and is not directly used in the failure correlations.

The failure correlation plot displays the current sample coefficients relative to the boundaries of available model data used to develop the failure correlation for the appropriate reactor type. Failure correlation for sample data points that lie within the corresponding boundary are generally perceived to be more reliable.

Figure 4-9 shows a typical failure correlation plot for a BWR data sample.

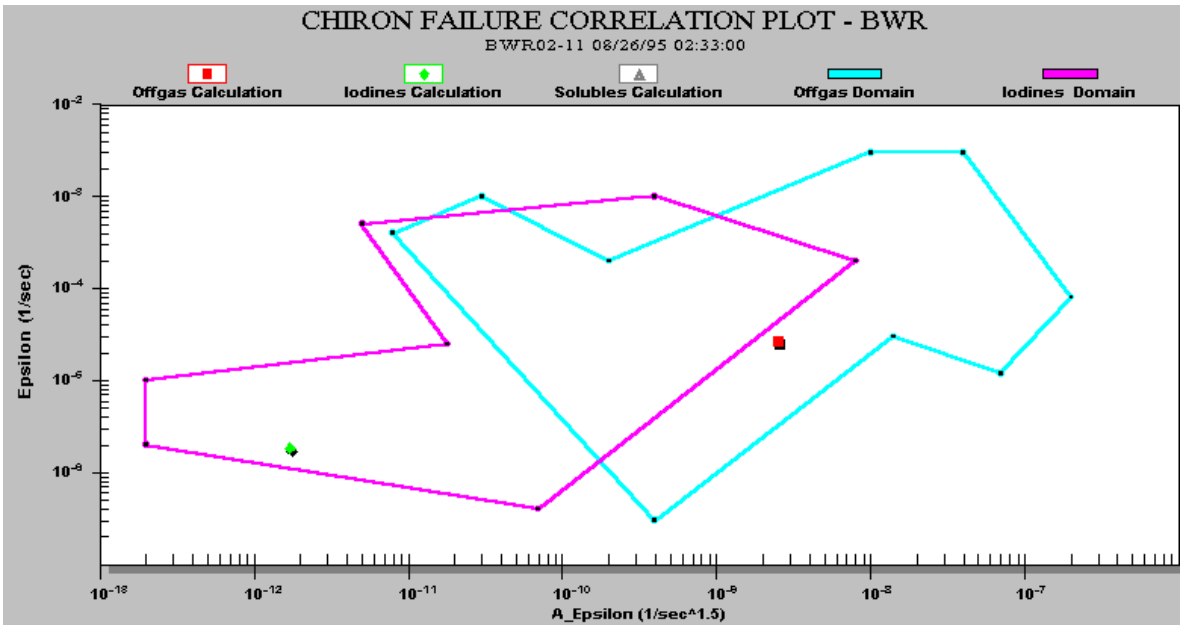

Figure 4-9
Failure Correlation Plot for BWRs

4.1.7 User Defined X Versus Y Plot

The last sample plot to discuss is the User Defined X versus Y plot. This is a general plot. It is intended to be user defined, with the user selecting from lists of allowable options. **This choice is not currently available and, therefore, appears grayed out in the drop-down menu.**

4.1.8 Editing Single-Sample Screen Plots

Single-sample screen plots are edited, exported, or printed in the same way as described in Section 2.5 , Steps 11 and 12 for the trending plots.

4.2 Trending Plots

Trend plots are available immediately after performing a batch analysis or by selecting the Trend Plots option from the trending menu. Selecting the option from the trending menu will generate a plot based on the cases already analyzed in the database.

4.2.1 Standard Trending Plots

Trend plots are selected from the dialog box shown in Figure 2-22. Each of the two list-boxes (one for the Y Axis and one for the X axis) contains 86 selectable functions for plotting. These are described below.

Selection #	Selection Title	Description
0	Power	Fraction of Rated Reactor Power
1	Xe-138 (rel rate)	Non-Fitted Activity, μCi/sec
2	Xe-135m (rel rate)	Non-Fitted Activity, μCi/sec
3	Kr-87 (rel rate)	Non-Fitted Activity, μCi/sec
4	Kr-88 (rel rate)	Non-Fitted Activity, μCi/sec
5	Kr-85m (rel rate)	Non-Fitted Activity, μCi/sec
6	Xe-135 (rel rate)	Non-Fitted Activity, μCi/sec
7	Xe-133 (rel rate)	Non-Fitted Activity, μCi/sec
8	I-134 (rel rate)	Non-Fitted Activity, μCi/sec
9	I-132 (rel rate)	Non-Fitted Activity, μCi/sec
10	I-135 (rel rate)	Non-Fitted Activity, μCi/sec
11	I-133 (rel rate)	Non-Fitted Activity, μCi/sec
12	I-131 (rel rate)	Non-Fitted Activity, μCi/sec
13	Tc-101 (rel rate)	Non-Fitted Activity, μCi/sec
14	Ba-141 (rel rate)	Non-Fitted Activity, μCi/sec
15	Cs-138 (rel rate)	Non-Fitted Activity, μCi/sec
16	Ba-139 (rel rate)	Non-Fitted Activity, μCi/sec
17	Sr-92 (rel rate)	Non-Fitted Activity, μCi/sec
18	Tc-99m (rel rate)	Non-Fitted Activity, μCi/sec
19	Sr-91 (rel rate)	Non-Fitted Activity, μCi/sec
20	Np-239 (rel rate)	Non-Fitted Activity, μCi/sec
21	Mo-99 (rel rate)	Non-Fitted Activity, μCi/sec
22	Te-132 (rel rate)	Non-Fitted Activity, μCi/sec
23	Ba-140 (rel rate)	Non-Fitted Activity, μCi/sec
24	Te-129m (rel rate)	Non-Fitted Activity, μCi/sec
25	Sr-89 (rel rate)	Non-Fitted Activity, μCi/sec
26	Cs-134 (rel rate)	Non-Fitted Activity, μCi/sec
27	Sr-90 (rel rate)	Non-Fitted Activity, μCi/sec
28	Cs-137 (rel rate)	Non-Fitted Activity, μCi/sec
29	Xe-138/I-131	Non-Fitted Activity (rel rate) Ratio
30	I-131/Xe-133	Non-Fitted Activity (rel rate) Ratio
31	I-134/I-131	Non-Fitted Activity (rel rate) Ratio

Selection #	Selection Title	Description
32	Xe-138/Xe-133	Non-Fitted Activity (rel rate) Ratio
33	Cs-134/Cs-137	Non-Fitted Activity (rel rate) Ratio
34	Sr-90/Sr-92	Non-Fitted Activity (rel rate) Ratio
35	Np-239/(Sum15+Np)	Non-Fitted Activity (rel rate) Ratio
36	OG Sum-of-Six	Non-Fitted Release Rates, μCi/sec
37	OG Sum-of-Six	Fitted Release Rates, μCi/sec
38	OG Sum6 Tramp	Fitted Release Rates, μCi/sec
39	OG Sum6 nonTramp	Fitted Release Rates, μCi/sec
40	ID Sum-of-Five	Non-Fitted Release Rates, μCi/sec
41	ID Sum-of-Five	Fitted Release Rates, μCi/sec
42	ID Sum5 Tramp	Fitted Release Rates, μCi/sec
43	ID Sum5 nonTramp	Fitted Release Rates, μCi/sec
44	Solubles Sum	Non-Fitted Release Rates, μCi/sec
45	Solubles Sum	Fitted Release Rates, μCi/sec
46	Solubles Tramp	Fitted Release Rates, μCi/sec
47	Xe-138 (rel rate)	Fitted Release Rate Activity, μCi/sec
48	Xe-135m (rel rate)	Fitted Release Rate Activity, μCi/sec
49	Kr-87 (rel rate)	Fitted Release Rate Activity, μCi/sec
50	Kr-88 (rel rate)	Fitted Release Rate Activity, μCi/sec
51	Kr-85m (rel rate)	Fitted Release Rate Activity, μCi/sec
52	Xe-135 (rel rate)	Fitted Release Rate Activity, μCi/sec
53	Xe-133 (rel rate)	Fitted Release Rate Activity, μCi/sec
54	I-134 (rel rate)	Fitted Release Rate Activity, μCi/sec
55	I-132 (rel rate)	Fitted Release Rate Activity, μCi/sec
56	I-135 (rel rate)	Fitted Release Rate Activity, μCi/sec
57	I-133 (rel rate)	Fitted Release Rate Activity, μCi/sec
58	I-131 (rel rate)	Fitted Release Rate Activity, μCi/sec
59a	Epsilon OG	Calculated by Least Sqs. Fit to OG
59b	Epsilon ID	Calculated by Least Sqs. Fit to ID
60a	AEpsilon OG	Calculated by Least Sqs. Fit to OG
60b	AEpsilon ID	Calculated by Least Sqs. Fit to ID
61a	C OG	Calculated by Least Sqs. Fit to OG
61b	C ID	Calculated by Least Sqs. Fit to ID
62a	Fit Error OG	R-squared Goodness of Fit, OG
62b	Fit Error ID	R-squared Goodness of Fit, ID
63a	PuFrac OG	Pu-239 Fission Yield Ratio from OG
63b	PuFrac ID	Pu-239 Fission Yield Ratio from ID
64a	Failures OG	No. of Failures by Gen. OG Model
64b	Failures ID	No. of Failures by Gen. ID Model
65	Comb. Model Fail.	Number of Failed Rods by CFM

Selection #	Selection Title	Description
66	Comb. Model RPF	Rod Pwr Fact. Calculated by CFM
67	Sample RPF	Inputted Sample Rod Power Factor
68	INPO FRI	"Daily FRI", Regardless of Power
69	N-13 (rel rate)	Non-Fitted Activity, μCi/sec
70	Rb-89 (rel rate)	Non-Fitted Activity, μCi/sec
71	Nb-97 (rel rate)	Non-Fitted Activity, μCi/sec
72	Ar-41 (rel rate)	Non-Fitted Activity, μCi/sec
73	Cu-64 (rel rate)	Non-Fitted Activity, μCi/sec
74	Na-24 (rel rate)	Non-Fitted Activity, μCi/sec
75	Zr-97 (rel rate)	Non-Fitted Activity, μCi/sec
76	Y-90 (rel rate)	Non-Fitted Activity, μCi/sec
77	Cr-51 (rel rate)	Non-Fitted Activity, μCi/sec
78	Fe-59 (rel rate)	Non-Fitted Activity, μCi/sec
79	Hf-181 (rel rate)	Non-Fitted Activity, μCi/sec
80	Zr-95 (rel rate)	Non-Fitted Activity, μCi/sec
81	Co-58 (rel rate)	Non-Fitted Activity, μCi/sec
82	Zn-65 (rel rate)	Non-Fitted Activity, μCi/sec
83	Mn-54 (rel rate)	Non-Fitted Activity, μCi/sec
84	Co-60 (rel rate)	Non-Fitted Activity, μCi/sec
85	Sample BU	Burnup Calculated from Sample

Note, that Selections 59-64 are all double selections. This means that the items named as "a" and "b" are selected together and *co-plotted* in the same graph.

4.2.2 User Defined Trending Plots

User-defined trending plots are intended to enable the user to plot a wide selection of activities, or expressions based on activities, as functions of time or as functions of other such expressions. **This option is not currently available.**

4.2.3 Editing Trending Plots

Editing, exporting, and printing of trend-plots is described in Section 2.5, Steps 11 and 12.

4.3 Screen Reports

The list of available single-sample screen reports is shown below:

- Offgas Activity and Fit Summary
- Iodine Activity and Fit Summary
- Solubles Activity and Fit Summary
- Offgas RB Summary
- Iodines RB Summary
- Solubles RB Summary
- Activity Ratio Summary
- QA Report

These reports are accessed from the drop-down menu of the Analysis Summary screen (see Figure 2-20). In addition, a general CHIRON information screen report is available from the CHIRON main window by clicking on "Help" and the "About CHIRON" option.

The following subsections explain each report in detail and provide illustrations of sample reports.

4.3.1 Offgas Activity Summary Report

The Offgas Activity Summary screen report shows both the measured activities and the corresponding values on the best fit curve for the analyzed sample. The screen also shows the values of all three fit coefficients, the R^2-value (statistical "Goodness of Fit" parameter, see Chapter 6), the final convergence error, and the number of iterations needed for convergence. A sample Offgas Activity Summary screen report is shown in Figure 4-10.

Notably, this screen does not report the Pu^{239} yield fraction that results from the sample analysis, nor does it report whether the "three-coefficient fit" was accepted or not. This information is found in the Sample Analysis and Fit Summary screen.

Reasons for fit rejection are non-convergence, or a negative C-value, resulting from the least-squares analysis. In any of these events the ε-value will be *set* to zero, and a two-coefficient fit will then be provided. The "C" and "Aε" coefficients from that calculation will then be the values reported in the present screen. If the C-value is still negative, the sample will be rejected. In batch analysis, such samples will be left out of the trending analysis.

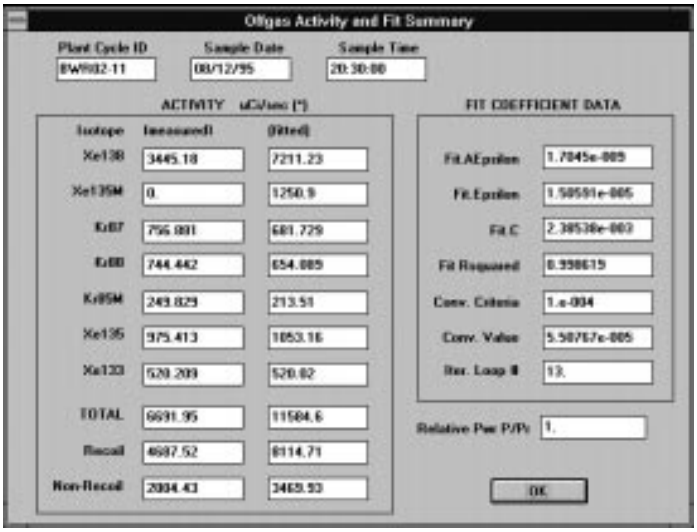

Figure 4-10
Offgas Activity Summary Report

4.3.2 Iodines Activity Summary Report

The Iodines Activity Summary screen report is analogous to the Offgas Activity Summary screen report discussed in the previous subsection. A sample Iodines Activity Summary screen report is shown in Figure 4-11.

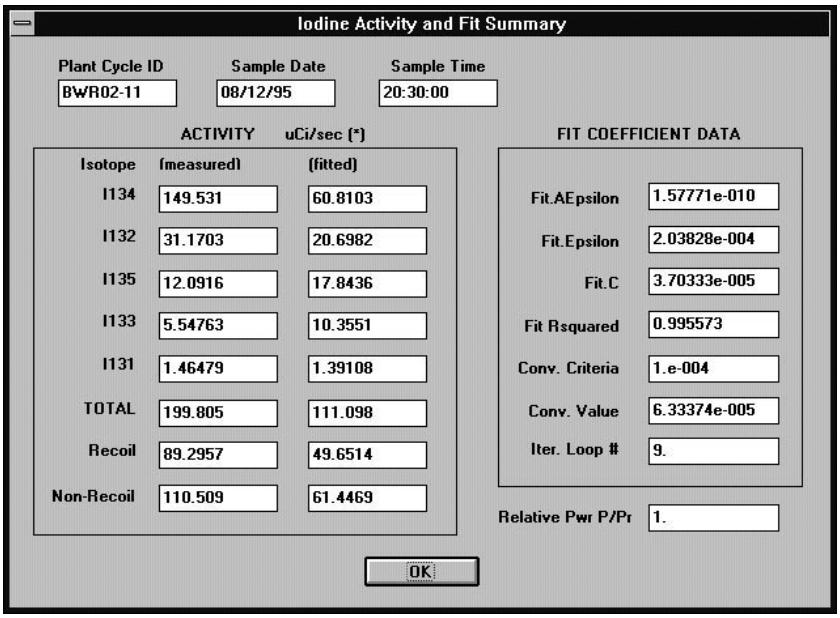

Figure 4-11
Iodines Activity Summary Report

4.3.3 Solubles Activity Summary Report

The Solubles Activity Summary screen report is analogous to the Offgas Activity Summary screen report. See Section 4.3.1 for a discussion. It is noted that this report only displays eight out of the 15 fission product solubles activities. A sample Solubles Activity Summary screen report is shown in Figure 4-12.

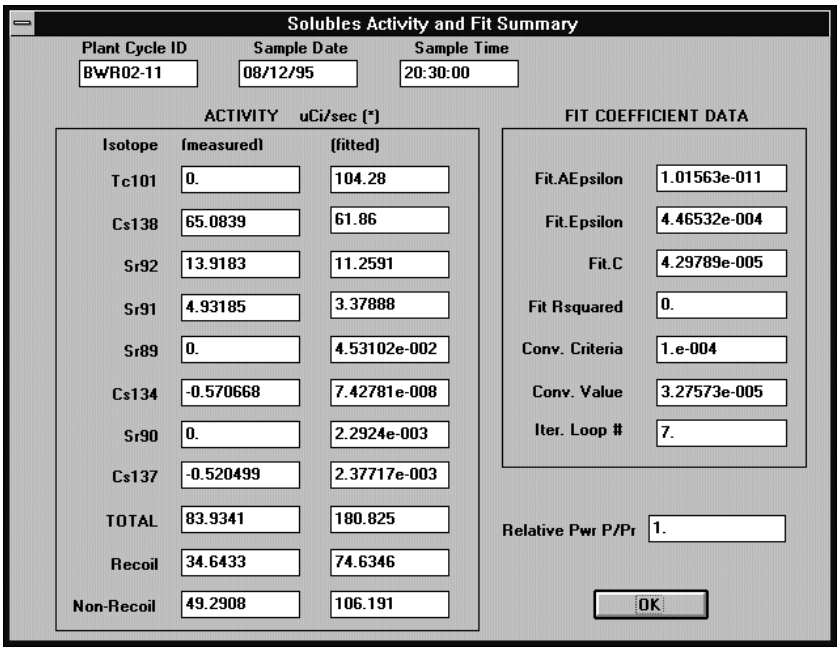

Figure 4-12
Solubles Activity Summary Report

4.3.4 Offgas Release to Birth Summary Report

The Offgas Release to Birth Summary screen report shown in Figure 4-13 presents the offgas datapoints, both measured and fitted, that appear in the Offgas and Iodines R/B versus λ plot (Figure 4-1 in Section 4.1.1).

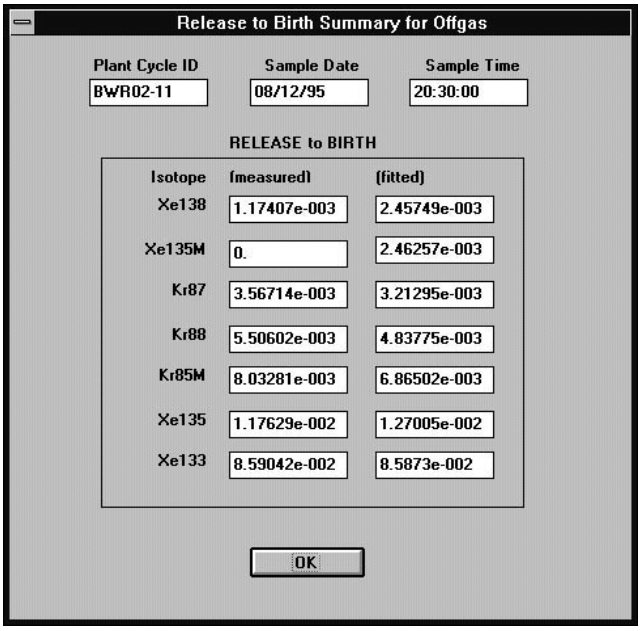

Figure 4-13
Offgas Release to Birth Summary Report

4.3.5 Iodines Release to Birth Summary Report

The Iodines Release to Birth Summary Summary screen report shown in Figure 4-14 presents the iodines datapoints, both measured and fitted, that appear in the Offgas and Iodines R/B versus λ plot (Figure 4-1 in Section 4.1.1).

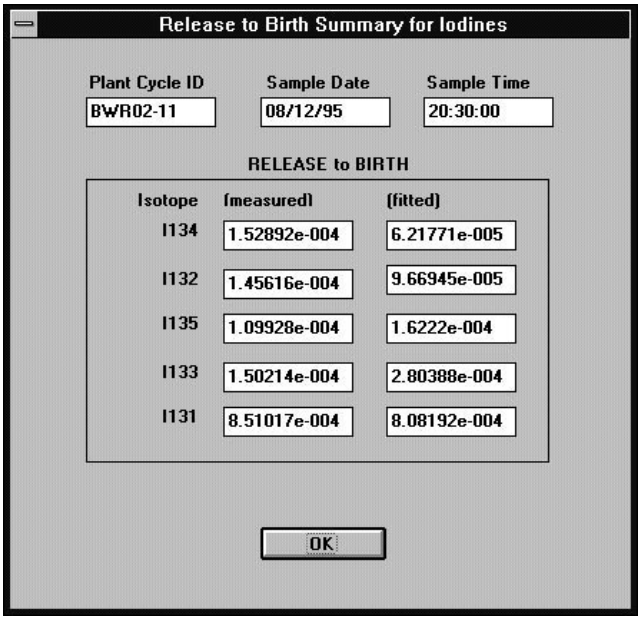

Figure 4-14
Iodines Release to Birth Summary Report

4.3.6 Solubles Release to Birth Summary Report

The Solubles Release to Birth Summary screen reportshown in Figure 4-15 presents a selection of eight out of the 15 fission product solubles activities, both measured and fitted, that appear in the Solubles R/B versus λ plots (Figure 4-2 and 4-4 in Section 4.1.2).

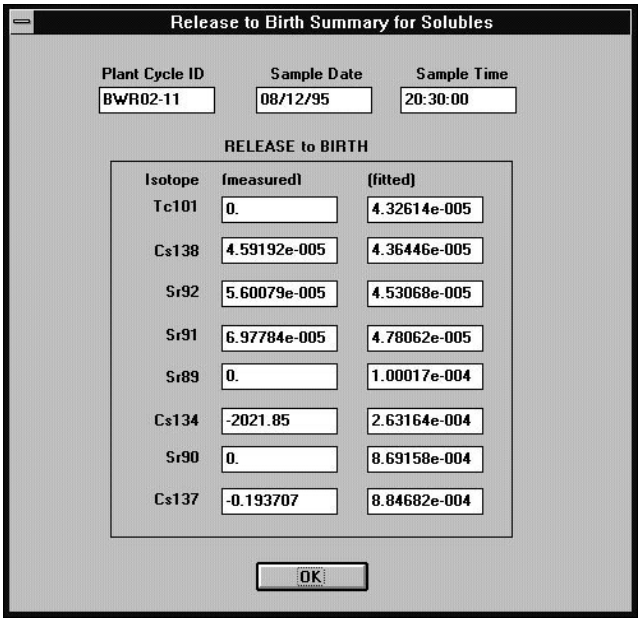

Figure 4-15
Solubles R/B versus λ Fit Summary Report

4.3.7 The Activity Ratio Summary Report

The Activity Ratio Summary Report (Figure 4-16) shows important activity ratios for the sample, as well as the burnup value calculated from the Cs-ratio, when available.

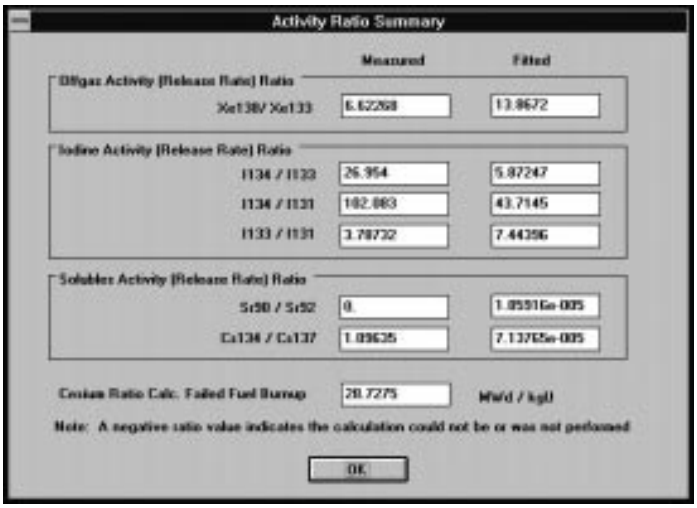

Figure 4-16
Activity Ratio Summary Report

4.3.8 The QA Report

The QA report provides all input and output data for the current single-sample analysis, including plant configuration data, model parameter selections, calculational options settings, model versions, and model constants. This file is intended to provide a complete QA record for any single sample, so that the calculation may be reproduced independently of the current database. This report is created upon request by selecting "Generate QA Report" or "Generate and View QA Report" from the "Reports" drop-down menu of the Analysis Fit Summary Results screen (see Figure 2-20).

4.3.9 The CHIRON Configuration Screen Report

The CHIRON Configuration report provides the revision history for the CHIRON code. This report is accessed from the CHIRON main window by clicking on "Help" and selecting the " About CHIRON" menu option.

4.4 Printed Reports

4.4.1 The QA Report

The QA report described in Section 4.3.8 can be printed. An example of a complete report text is shown in Appendix C.

4.4.2 The Calculation Log Report

The Calculation Log Report is available for single sample analysis only. To generate the log report, the "Enable calculation log file" box must be checked in the Output Options screen. (Accessed in main window under "options" menu, "Output Options" option.) A log report is generated for every single sample analysis performed until you disable (uncheck) the box in the Output Options screen. The log report file is overwritten for each new sample analyzed.

The Calculation Log Report is written to a text-file named "chicalc.log" which can be read into and printed by any text editor. The "chicalc.log" file can be large, on the order of 60 printed pages. This file is primarily of use for debugging purposes.

4.4.3 The ASCII Dump Files

The ASCII Dump Files can be generated for batch sample analysis only. A total of ten ASCII files are generated when this option is invoked. A detailed

description of the generation, use, format, and contents of these 10 ASCII dump files is provided in Appendix D.

5

THE CHIRON DATABASE

5.1 Database Overview

CHIRON is designed around a relational database system for the storage of the raw data and the analysis results. This allows the user to easily access and analyze the individual samples and to observe trends in the data through the trend plot features.

In order to provide flexibility in the database platform, CHIRON accesses data through a standard interface with ODBC 2.1 drivers. The ODBC interface allows CHIRON to access a variety of different database formats through a common interface. With this interface, CHIRON users can maintain their data in a Microsoft Access, Oracle, Paradox, or other database format that has an ODBC driver. CHIRON was developed using the Microsoft Access driver and all of the sample databases are in this format. The ODBC 2.1 driver for Microsoft Access corresponds to Microsoft Access Version 2.0. CHIRON has not been tested with any other database platform.

5.2 Database Structure

The CHIRON database is made up of six tables: samples, plant_data, failures, user_preferences, units, and unit_types. The contents of each of the tables is summarized below, but the detailed list of all of the data fields can be found in Appendix E.

The samples table contains all of the coolant sample data. This includes the sample date, reactor power, and the activity level for each of the nuclides. This table also contains the units defined for each value at the time the sample was entered. The data in this table corresponds with the data shown on the Add Sample dialog box (see Figure 3-6).

The plant_data table contains the plant specific data that does not change during a plant cycle. This includes the plant type (BWR or PWR), rated power, number of fuel rods, etc. as well as flags and other values that impact the calculation.

The failures table contains the results of the analysis for each of the samples. The values include the fit coefficients determined by the calculation and the activity levels for each of the nuclides.

The user_preferences table contains the units that the user has requested for future data input. This may be changed at any time by the user, but changing the units does not affect samples previously entered into the database.

The units table contains a list of the available units and the conversion factors to convert the input value to the cardinal unit. CHIRON reads this table to obtain the conversion factors.

The unit_types table provides a map of which units are available for each unit category. For example, the reactor power can be entered in either %P, FracP, or MWth. This table, in conjunction with the units table, generates the pull down boxes on the Sample Data Units dialog box (see Figure 3-5).

5.3 Creating a New Database

The typical CHIRON installation installs a blank database, chiblank.mdb, containing no data so that users can generate their own databases. It is highly recommended that users make a copy of the blank database before adding data to it. The following steps create a new database called PlantA:

1. Using File Manager (File | Copy) or the copy command from an MS-DOS prompt, copy "chiblank.mdb" to "planta.mdb".
2. Start the CHIRON program and select ASelect Data Source≅ from the Data menu.
3. From the SQL Data Sources Dialog, select New. From this point on, the steps are shown in detail in Section 2, steps 7.B through 7.D using APlantA≅ as the data source name and planta.mdb as the database name. The steps are quickly summarized below in steps 4-7.
4. Select the Microsoft Access Driver and click OK.
5. Register the database as APlantA≅ and click Select.
6. Select planta.mdb and click OK.
7. Check that you are registering planta.mdb as APlantA≅ and click OK.
8. Select APlantA≅ and click OK. The new database is now open.
9. From the CHIRON main window, add a plant configuration record by choosing the Options menu | Plant Configuration | Add New Plant.

10. Sample data can now be added using the Data menu and the New option as described in Section 3.3 of this manual.

5.4 Compacting a Database

The ODBC interface provides a method of compacting a database to reduce the size of the database file. This feature is only necessary when you have deleted a large number of records from the database. The database typically does not recover that space until it is compacted.

The steps below give the user the option of compacting a database into itself or to a new database. If the user selects compacting a database into itself, there is a chance that if the computer is interrupted, the database could be lost. It is wise to back up a database before compacting it into itself. If the user selects compacting into a new database, the risk of lost data is significantly reduced. However, the user must either register this new database or copy the compacted database over the original one. The following steps compact a database:

1. From the CHIRON main window, choose the Data menu and ASelect Data Source≅.
2. From the SQL Data Sources dialog box, select "New".
3. Select the "Microsoft Access Driver" and Click OK.
4. A dialog box opens as shown in Figure 5-1. Click "Compact".

Figure 5-1
ODBC Access Setup Box

5. A new box appears similar to that shown in Figure 5-2. Select a database you would like to compact from the list of database names and click OK.

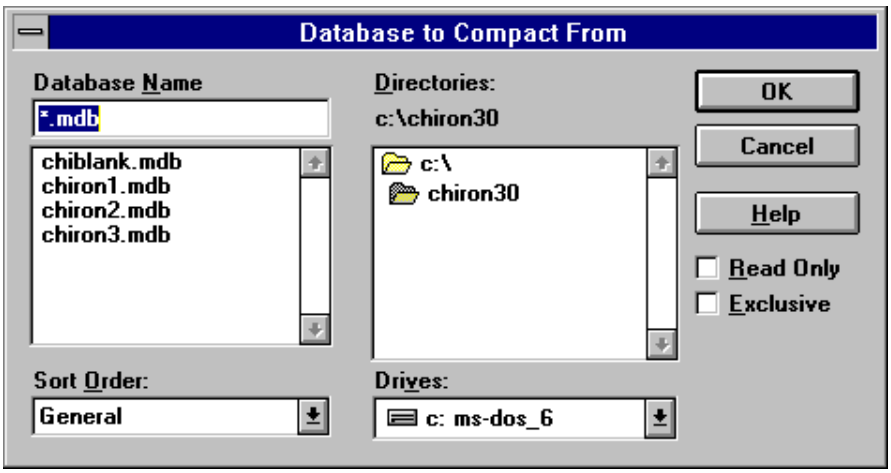

Figure 5-2
Compact Database Dialog Box

6. To compact the database into itself, select the same database name from the dialog box and click OK. Alternatively, the user can type in a new database name and click OK. If a new name is selected, that name must be registered before it can be used by CHIRON.

7. If you chose to compact the database into itself, a warning box will appear informing you that you are about to overwrite an existing file. Click Yes if this is what you want to do.

8. The compacting process begins and when it is finished a box appears telling you it compacted the database successfully.

5.5 Converting a CHIRON 2.3 Database to CHIRON 3.0

The database conversion program DBConv reads in a set of six ASCII files (the "ASCII Dump") created by CHIRON for DOS, Version 2.2 or later and writes out a single file containing all of the raw sample input data. The ASCII files must be available in the directory containing CHIRON for WINDOWS. The ASCII Dump filenames consist of a character string (up to 7-characters provided by the user) followed by a number from zero to five, and with the file extension ".csv".

To use DBConvert, double click on the DBConvert icon from the CHIRON group in the WINDOWS program manager. A MS-DOS window appears. DBConvert prompts the user for the following information:

1. The base name of the CHIRON output (ASCII dump) files. This is the 7-character string entered above. After entering the characters, press “Enter” and you will be prompted for the next item.

2. The Plant Identifier as it appears in CHIRON (up to five-character string). Note this is case sensitive.

3. The Cycle Identifier as an integer.

4. The SJAE Flow, in cc/sec. This number is only needed for BWRs. If the plant is a PWR, enter zero.

DBConvert generates an output file with one line for each sample date/time, which will represent a record in the database. The output filename is formed by combining the plant name string, the plant cycle number, and an extension .txt (e.g. Susq09.txt) Each record in the file is assigned the user supplied plant name and cycle number. DBConvert expects the data in the ASCII dump files to be from one plant cycle.

* * * Note: The user specified plant name is used to generate the "Plant-cycle ID" for the ACCESS database. Since the Plant-cycle ID is used in ACCESS in a case-sensitive manner, it is important that the user specified five-character Plant Identifier be entered exactly (case sensitive) as it is to appear in the Plant Configuration table within ACCESS.

The output file generated by DBConvert is a valid "File Read" input file to CHIRON for WINDOWS. Before reading the file into CHIRON for Windows, the user must create a "Plant Configuration" entry for the plant-cycle being loaded. This is provided through the Add Plant Configuration dialog box in CHIRON. The configuration information can best be retrieved from the "QA" report, printable from the CHIRON DOS version after completing any single sample analysis within the Plant-cycle ID data set. The "QA" report is found in the CHIRON DOS version under the menu "Reports", submenu "Hard Copy Reports".

Follow the instructions in Section 3 for the AFile Read≅ input option to CHIRON.

6

CHIRON THEORY

The theoretical basis for the CHIRON analysis is contained in References 1-3. This section presents all the logical steps in the mathematical derivations, including a discussion of the limiting assumptions made.

6.1 FORMULATION OF THE BASIC EQUILIBRIUM EQUATIONS

The change in inventory with time of a given radioactive nuclide, subscripted i, in the reactor coolant in the presence of X failed fuel rods can be written in terms of the primary production and removal components as:

$$\frac{dN_i^c}{dt} = \sum_{k=1}^{X} N_{ik}^v \, \varepsilon_{ik} + \dot{N}_{Ti} - (\lambda_i + \beta + \phi) N_i^c \qquad \text{(Eq. 6-1)}$$

where

N_i^c = number of atoms of nuclide i in the coolant.

N_{ik}^v = number of atoms of nuclide i in the void volume of failed rod k.

ε_{ik} = fraction of atoms of nuclide i released from the void space of failed rod k to the coolant per unit of time.

λ_I = decay constant for nuclide i (1/sec) (see built-in data in Table 6-1).

β = primary coolant cleanup rate (1/sec).

ϕ = coolant (or steam) carryover rate (1/sec) [= 0 for PWRs].

$\dot{N}_{TI}$ = rate of isotope deposition to the coolant from tramp sources.

Table 6-1
Isotopic Decay Data and Fission Yields

Isotope	Decay Constant, sec^{-1}	Half-life	Yield from U^{235}	Yield from Pu^{239}
Xe-138	8.136e-4	14 min.	0.0628	0.0489
Xe-135m	7.771e-4	15 min.	0.0106	0.0156
Kr-87	1.520e-4	1.3 hrs.	0.0254	0.0095
Kr-88	6.876e-5	2.8 hrs.	0.0358	0.0132
Kr-85m	4.298e-5	4.5 hrs.	0.0131	0.0055
Xe-135	2.100e-5	9.2 hrs.	0.0663	0.0747
Xe-133	1.517e-6	5.3 days	0.0677	0.0697
I-134	2.196e-4	53 min.	0.0761	0.0729
I-132	8.426e-5	2.3 hrs.	0.0421	0.0527
I-135	2.924e-5	6.6 hrs.	0.0631	0.0641
I-133	9.257e-6	21 hrs.	0.0677	0.0693
I-131	9.977e-7	8.0 days	0.0284	0.0374
Te-101	8.136e-4	14 min.	0.0504	0.0592
Ba-141	6.313e-4	18 min.	0.0587	0.0533
Cs-138	3.588e-4	32 min.	0.0672	0.0545
Ba-139	1.387e-4	1.4 hrs.	0.0648	0.0564
Sr-92	7.105e-5	2.7 hrs.	0.0595	0.0299
Tc-99m	3.198e-5	6.0 hrs.	0.0540	0.0541
Sr-91	2.031e-5	9.5 hrs.	0.0592	0.0249
Np-239	3.414e-6	2.3 days	0.0290	0.0290
Mo-99	2.916e-6	2.8 days	0.0613	0.0615
Te-132	2.468e-6	3.3 days	0.0419	0.0515
Ba-140	6.273e-7	13 days	0.0632	0.0557
Te-129m	2.402e-7	33 days	0.0012	0.0027
Sr-89	1.589e-7	51 days	0.0485	0.0171
Cs-134	1.067e-8	2.1 yrs.	0.00000045	0.0000032
Sr-90	7.579e-10	29 yrs.	0.0592	0.0212
Cs-137	7.302e-10	30 yrs.	0.0626	0.0669
N-13	1.16 e-3	10 min.	N/A	N/A
Rb-89	7.70 e-4	15 min.	not used	not used
Nb-97	1.60 e-4	1.2 hrs.	not used	not used
Ar-41	1.05e-4	1.8 hrs.	N/A	N/A
Cu-64	1.49e-5	13 hrs.	N/A	N/A
Na-24	1.28e-5	15 hrs.	N/A	N/A
Zr-97	1.13e-5	17 hrs.	not used	not used
Y-90	3.00e-6	2.7 days	not used	not used
Cr-51	2.88e-7	28 days	N/A	N/A
Fe-59	1.78e-7	45 days	N/A	N/A
Hf-181	1.78e-7	45 days	N/A	N/A
Zr-95	1.23e-7	65 days	N/A	N/A
Co-58	1.12e-7	72 days	N/A	N/A
Zn-65	3.27e-8	245 days	N/A	N/A
Mn-54	2.65e-8	302 days	N/A	N/A
Co-60	4.18e-9	5.3 yrs.	N/A	N/A

N/A indicates that the isotope is not considered a significant fission product for the CHIRON analysis

The first term on the right-hand side of Eq. 6-1 represents the isotope contribution from failed fuel rods. The second term represents the contribution from tramp fissions. The third term is the isotopic removal due to decay, cleanup, and, in the case of iodine isotopes in BWRs, carryover with steam.

The number of nuclide atoms in the void volume of a given failed fuel rod can be determined from a mass balance of nuclide i within the void region of the failed rod:

$$\frac{dN_{ik}^{v}}{dt} = N_{ik}^{f}\ \nu_{ik} - (\varepsilon_{ik} + \lambda_i) N_{ik}^{v} \qquad \text{(Eq. 6-2)}$$

where:

N_{ik}^{f} = number of atoms of nuclide i within the fuel region of rod k at any instant.

ν_{ik} = Fraction of atoms of nuclide i released from the fuel into the void region of fuel rod k per unit of time.

An expression for the number of atoms of the nuclide in the fuel region of the rod, N_{ik}^{f}, can be developed by considering a mass balance within the fuel region:

$$\frac{dN_{ik}^{f}}{dt} = F_k\ y_{ik} - (\nu_{ik} + \lambda_i) N_{ik}^{f} \qquad \text{(Eq. 6-3)}$$

where:

F_k = fission rate in rod k.

y_{ik} = fractional yield of nuclide i per fission in rod k (see data in Table 6-1).

If the analysis is restricted to equilibrium conditions, then the temporal derivative in each of Eqs. 6-1, 6-2 and 6-3 is zero. From the equilibrium form of Eq. 6-3:

$$N_{ik}^{f} = \frac{F_k\ y_{ik}}{(\nu_{ik} + \lambda_i)} \qquad \text{(Eq. 6-4)}$$

If it is assumed that the diffusion rate through the fuel for all isotopes to be considered (iodines and noble gases) is much smaller than the nuclide decay rate, then Eq. 6-4 reduces to:

$$N_{ik}^{f} = \frac{F_k \, y_{ik}}{\lambda_i} \qquad \text{(Eq. 6-5)}$$

The equilibrium form of Eq. 6-2 with Eq. 6-5 substituted for N_{ik}^{f} yields:

$$N_{ik}^{v} = \frac{\nu_{ik} \, F_k \, y_{ik}}{\lambda_i \left(\varepsilon_{ik} + \lambda_i\right)} \qquad \text{(Eq. 6-6)}$$

An expression for the rate of isotope deposition into the coolant from the tramp fuel sources ($\dot{N}_{Ti}$ in Eq. 6-1) can be developed by assuming that the release is composed of two components. These components are: (1) direct release of the isotope into the coolant, and (2) diffusional release of the isotopes into the coolant. The total release rate term can be written as:

$$\dot{N}_{Ti} = \gamma \; F_{Ti} \, y_{Ti} + \nu_{Ti} N_{ti} \qquad \text{(Eq. 6-7)}$$

where:

γ = Fraction of total isotopic production that is released directly to the coolant.

ν_{Ti} = Rate of diffusion of the isotope to the coolant.

F_{Ti} = Fission rate of the tramp fuel in the core.

y_{Ti} = Fractional yield of nuclide i per fission of tramp fuel.

N_{ti} = Isotope concentration resulting from tramp fuel fissions.

The isotope concentration can be determined from a mass balance in the tramp diffusion region:

$$\frac{dN_{Ti}}{dt} = (1-\gamma) F_{Ti} \, y_{Ti} - (\nu_{Ti} + \lambda_i) N_{Ti} \qquad \text{(Eq. 6-8)}$$

The diffusion rate constant ν_{Ti} should be substantially less than the decay rate (as was the case for diffusion through the fuel pellet). In addition, if steady state conditions are applied to Eq. 6-8, then the isotopic concentration in the tramp diffusion region becomes:

$$N_{Ti} = \frac{(1-\gamma)\, F_{Ti}\, y_{Ti}}{\lambda_i} \qquad \text{(Eq. 6-9)}$$

Substitution of Eq. (6-9) into Eq. (6-7) yields:

$$\dot{N}_{Ti} = \left[\gamma + (1-\gamma)\, \frac{\nu_{Ti}}{\lambda_i}\right] F_{Ti}\, y_{Ti} \qquad \text{(Eq. 6-10)}$$

Substituting Eq. 6-6 and Eq. 6-10 into Eq. 6-1 and considering only the equilibrium form of the equation yields:

$$(\lambda_i + \beta + \phi)\, N_i^c = \sum_{k=1}^{X} \frac{\varepsilon_{ik}\, \nu_{ik}\, F_k\, Y_{ik}}{\lambda_i (\varepsilon_{ik} + \lambda_i)} + \left[\gamma + (1-\gamma)\, \frac{\nu_{Ti}}{\lambda_i}\right] F_{Ti}\, y_{Ti}$$

(Eq. 6-11)

With some approximations and simplifications, Eq. 6-11 can be expressed in a form that will relate the measurement of coolant activity to fuel performance and failure estimates. Below is a description of the various assumptions applicable to iodine and noble gas coolant activity analysis in light water reactors.

The number of nuclide atoms in the coolant, N_i^c, in Eq. 6-11, can be determined from the measured coolant activity concentration, M_i^c, since

$$M_i^c\, V_c = N_i^c\, \lambda_i \qquad \text{(Eq. 6-12)}$$

where:

M_i^c = measured coolant activity concentration (disintegration/sec/cc).

V_c = volume of water (hot) in the primary coolant system (cc).

The rod escape rate coefficient, ε_{ik}, is primarily affected by the size of the defect and the potential for chemical interaction with other elements in the fuel void region. For the case of iodine sampling, each nuclide is an isotope of the same element (iodine). Thus the chemical interaction for all nuclides can be considered to be the same. Similarly, each nuclide in a noble gas sample is chemically inert. Thus the rod escape rate coefficient for a given sample (either iodine or noble gas) is independent of the nuclide, i, in that sample. ***If it is further assumed that the defect size does not vary significantly from rod to rod,*** then the escape rate coefficient is effectively a constant value for all nuclides in a particular sample (iodine or noble gas) at any given time. Thus, for either an iodine or noble gas sample,

$$\varepsilon_{ik} = \varepsilon = \text{a constant} \qquad \text{(Eq. 6-13)}$$

for that particular sample.

If it is further assumed that release from the fuel matrix is diffusion dependent, then ***the Booth formulation*** (Reference 4) for diffusional release from the fuel may be used. Based upon this formulation, the fuel escape rate coefficient is proportional to the square root of the nuclide decay constant:

$$\nu_{ik} \propto \sqrt{D'_k \, \lambda_i}$$

where:

D'_k = diffusion rate constant for fission products of interest in rod k.

This relationship can be rewritten in the form

$$\nu_{ik} = a'_k \sqrt{\lambda_i} \qquad \text{(Eq. 6-14)}$$

where:

a'_k = a constant including diffusion effects and rod geometry factors.

It should be noted that the geometry factors composing a'_k are approximately constant for all light water fuel rods. However, the diffusion effects are affected by rod temperature and thus a'_k does vary somewhat from rod to rod due to the temperature dependence.

Similarly, for tramp diffusion,

$$\nu_{Ti} = D_T \sqrt{\lambda_i} \qquad \text{(Eq. 6-15)}$$

where D_T is a Booth diffusion related constant for tramp diffusion. Typical values for D_T are 5.0e-5 $sec^{-1/2}$ for offgas and 3.5e-5 $sec^{-1/2}$ for iodines (Reference 5).

The defective rod fission rate factor in rod k, F_k, can be expressed as:

$$F_k = F f_{Fk} \qquad \text{(Eq. 6-16)}$$

where:

F = rod fission rate at core average power of an average power fuel rod.

f_{Fk} = ratio of fission rate in defective rod k to fission rate of an average power rod.

Note that f_{Fk} is primarily affected by the ratio of power in rod k to core average power, although there may be some secondary effects due to enrichment and burnup difference.

As a final approximation, the nuclide yield term, y_{ik}, in Eq. 6-11 can be assumed to be of the form

$$y_{ik} = y_i \, f_{yk} \qquad \text{(Eq. 6-17)}$$

where:

y_i = fractional yield of nuclide i at an exposure equivalent to the average exposure of the defective rods in the core.

F_{yk} = ratio of the nuclide yield for any nuclide in defective rod k to the nuclide yield at the average defective rod exposure.

Note that f_{yk} is primarily a function of the Pu fission fraction of the defective rod relative to an equivalent rod that behaves like the composite defective rods in the core. Also, the form of Eq. 6-17 assumes that f_{yk} is the same for each nuclide, i, within the defective rod. In reality, this is not the case since each nuclide yield is affected differently as the Pu fission fraction changes (primarily due to burnup). However, the overall range of yield values for any given nuclide is fairly limited over the entire burnup range of the rod, so the assumption of constant nuclide yield ratio for each nuclide is reasonably acceptable.

Substituting Eqs. 6-12 through 6-17 into Eq. 6-11 and rearranging terms yields:

$$\frac{(\lambda_i + \beta + \phi)}{\lambda_i} M_i^c V_c = \frac{\varepsilon F y_i \sum_{k=1}^{X} \left(a'_k f_{Fk} f_{yk}\right)}{\sqrt{\lambda_i}\,(\varepsilon + \lambda_i)} + \left[\gamma + (1-\gamma)\frac{D_T}{\sqrt{\lambda_i}}\right] F_{Ti}\, y_{Ti} \quad \text{(Eq. 6-18)}$$

At this point some simplifying terminology can be introduced to rewrite Eq. 61-18 into its final form:

$$R_i = \frac{a\,\varepsilon}{\sqrt{\lambda_i}\,(\varepsilon + \lambda_i)} + \xi_i C \quad \text{(Eq. 6-19)}$$

where:

$R_i \equiv \dfrac{(\lambda_i + \beta + \phi) M_i^c V_c}{F y_i \lambda_i}$ = "release to birth" ratio for nuclide i in the primary coolant.

$a \equiv \sum_{k=1}^{X} \left(a'_k f_{Fk} f_{yk}\right)$

$C \equiv \dfrac{F_T}{F}$ = ratio of tramp to fuel rod fission rates.

$\xi_i \equiv \left[\gamma + (1-\gamma)\dfrac{D_T}{\sqrt{\lambda_i}}\right]\left(\dfrac{y_{Ti}}{y_i}\right)$

The "release-to-birth" ratio is defined as the ratio of the total primary coolant release rate to the birth rate in one single rod. Thus, if a core has multiple defective rods, it is theoretically possible that the release-to-birth ratio can be greater than unity.

For any reactor coolant sample, the nuclide "release to birth" ratio, R_i, can be determined using the measured nuclide activity M_i^c, primary coolant system parameters (β, ϕ, and V_C), core average power (to determine fission rate F), and an estimate of the yield of the nuclide in the defective rods (y_i). Note that Eq. 6-19 is valid for ***each*** nuclide in the sample and that the unknown coefficients, a, ε, and C are the same for each nuclide in the sample, although the coefficient values for an iodine sample will differ from those of a noble gas sample. Therefore, if the coolant sample is composed of n nuclides, then Eq. 6-19 represents a set of n equations in three unknowns (a, ε, and C) that can be determined using non-linear least squares analysis. Once unique values of a, ε, and C have been determined for a coolant sample, these values can be used to determine specific information relating to fuel performance, such as number of defective rods, effective defect size, and core tramp contribution.

Section 6.1.1 describes the procedure for determining the coefficients a, ε, and C from a coolant sample using non-linear least squares analysis. Section 6.1.2 develops single isotopic group correlations for estimating the number of fuel rod failures from the least squares coefficients.

The solution of Eq. 6-19 for the unknown coefficients, a, ε, and C, requires that the nuclide yields, y_i, and the nuclide tramp diffusion coefficient, ξ_I, be known. In practice, appropriate values for these terms are usually not immediately apparent to the user. As a result, CHIRON provides a method for estimating these terms as a part of the normal sample analysis process.

The nuclide yield, y_i, is approximately a function of the quantity of Pu^{239} in the defective rods relative to the total quantity of fissile material. Since the fractional amount of Pu in the rods is a function of fuel burnup, the user may have specific insight into the appropriate value to use for the Pu fission fraction. CHIRON provides for the direct entry of this ratio. However, this level of insight into the specific nature of the failed fuel condition is usually rare. As a result, CHIRON also has the capability of estimating the value by solving Eq. 6-20 for several assumed values of Pu fission fraction, then utilizing the specific value that provides the best "Goodness-of-Fit". This best estimate of the Pu fission fraction is then reported to the user for informational purposes.

The diffusion release coefficient, ξ_i is determined from user specified values for the release fraction, γ in Eq. 6-7, and the tramp plutonium fraction. Since tramp material generally plates out on fuel surfaces as small particles, the depth of tramp material is usually small. As a result, most of the release of tramp is expected to be direct to the coolant. Under this condition, the direct release fraction, γ in Eq. 6-7, should be close to unity. In addition, the range of yield fractions for the various nuclides in a CHIRON sample analysis usually do not vary greatly over a wide range of burnups (i.e., Pu fraction). Under these assumptions, $\xi_i \approx 1$, which is the default value used by CHIRON. The user may, however, select to have CHIRON estimate a more appropriate value for ξ_i by providing estimates of the release fraction and, if desired, the tramp Pu fraction.

6.1.1 Least Squares Analysis for Performance Coefficients

As was noted in Section 6.1, the fuel performance coefficients (a, ε, and C) in Eq. 6-19 are the same for each nuclide in a reactor coolant sample. If the sample measures n distinct nuclides, then Eq. 6-19 represents n equations in three unknowns. If n > 3 then the coefficients can be determined using non-linear least squares analysis.

Once a least squares fit has been determined by CHIRON, a statistical quantity, R^2, also referred to as the "Goodness of Fit", is calculated. It is a measure of how closely the measured points fit the approximating curve determined by the fitting. The R^2-value is by definition between 0 and 1, with 1 indicating a perfect fit. For CHIRON analyses, R^2-values between 0.95 and 1.00 indicate a good fit.

The remainder of this section discusses how a specific algorithm has been developed for solving the non-linear least squares problem at hand, and determining the fuel performance coefficients of Eq. 6-19.

6.1.1.1 Determining Fuel Performance Coefficients for Normal Case

From classical least-squares analysis theory, the values of the coefficients a, ε, and C must minimize the sum of the squares of the error between the measured and predicted (using the coefficients) values of the coolant release to birth ratios. Mathematically the error, E, is defined as:

$$E = \sum_{i=1}^{n} \left[R_i - \frac{(a\,\varepsilon)}{\sqrt{\lambda_i}\,(\varepsilon + \lambda_i)} - \xi_i C \right]^2 \qquad \text{(Eq. 6-20)}$$

where:

E	=	sum of the squares of the errors (SSE) in predictions.
R_i	=	coolant "release to birth" ratio (known from coolant measurements).
λ_i	=	decay constant for nuclide i.
n	=	number of nuclides measured in the sample.
a, ε, C	=	constants to be determined by least-squares analysis.
ξ_i	=	tramp isotopic release correction factor.

In order for a, ε, and C to minimize E in Eq. 6-20, the derivative of E with respect to each coefficient must be zero. Thus

$$\frac{dE}{da} = \frac{dE}{d\varepsilon} = \frac{dE}{dC} = 0$$

It is mathematically convenient at this point to note, from Eq. 6-20, that the term (aε) could just as easily be considered a constant itself. The term (aε) can be uniquely determined from the least-squares analysis along with ε and C. The value of a, if it is desired, can then be determined as

$$a = (a\varepsilon) / \varepsilon$$

There will not always be a need to calculate "a" specifically, since the composite coefficient (aε) will suffice for predicting the number of failed rods in the core, in cases where the "General Failure Models" are used, as will be discussed in Section 6.1.2. Treating (aε) as a composite single coefficient yields the revised minimization requirements:

$$\frac{dE}{d(a\varepsilon)} = \frac{dE}{d\varepsilon} = \frac{dE}{dC} = 0 \qquad \text{(Eq. 6-21)}$$

Applying Eq. 6-21 to Eq. 6-20 yields:

$$\frac{dE}{d(a\varepsilon)} = \sum_{i=1}^{n} \frac{-2}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)} \left[R_i - \frac{(a\ \varepsilon)}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)} - \xi_i C \right] = 0 \qquad \text{(Eq. 6-22)}$$

$$\frac{dE}{d\varepsilon} = \sum_{i=1}^{n} \frac{2}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)^2} \left[R_i - \frac{(a\ \varepsilon)}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)} - \xi_i C \right] = 0 \qquad \text{(Eq. 6-23)}$$

$$\frac{dE}{dC} = \sum_{i=1}^{n} (-2)\xi_i \left[R_i - \frac{(a\ \varepsilon)}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)} - \xi_i C \right] = 0 \qquad \text{(Eq. 6-24)}$$

Expanding the summation to individual terms in each equation and dividing by the constant multipliers results in the following respective equations to be solved simultaneously for (aε), ε, and C:

$$\sum_{i=1}^{n} \frac{R_i}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)} = (a\varepsilon) \sum_{i=1}^{n} \frac{1}{\lambda_i\,(\varepsilon+\lambda_i)^2} + C \sum_{i=1}^{n} \frac{\xi_i}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)} \qquad \text{(Eq. 6-25)}$$

$$\sum_{i=1}^{n} \frac{R_i}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)^2} = (a\varepsilon) \sum_{i=1}^{n} \frac{1}{\lambda_i\,(\varepsilon+\lambda_i)^3} + C \sum_{i=1}^{n} \frac{\xi_i}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)^2} \qquad \text{(Eq. 6-26)}$$

$$\sum_{i=1}^{n} \xi_i R_i = (a\varepsilon) \sum_{i=1}^{n} \frac{\xi_i}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)} + C \sum_{i=1}^{n} \xi_i^2 \qquad \text{(Eq. 6-27)}$$

A review of Eqs. 6-25, 6-26, and 6-27 reveals that the two coefficients (aε) and C occur in linear form in each of the equations, while only ε appears non-linearly. It is, therefore, possible to express both (aε) and C explicitly in terms of ε, using any two of these three equations. These explicit relationships for (aε) and C can then be substituted into the third equation to yield a single non-linear equation in terms of ε only. Thus, the simultaneous solution to three non-linear equations can be reduced to finding the roots of a single non-linear (but continuous) equation.

Mathematically, the choice of which two of the three equations to solve explicitly for (aε) and C is irrelevant. There is, however, a numerical preference based

upon the desire to be able to calculate the remaining (non-linear) equation over a wide range of ε values, while searching for the roots of the equation. Inspection of Eqs. 6-25 and 6-26 reveals that as ε increases (approaches ∞), each term in these equations tends to a value of zero. Thus, an asymptote at zero will exist (in addition to the real roots of the equation) as ε increases. However, Eq. 6-27 does not exhibit this asymptotic behavior as ε increases. Therefore, roots of the equation (even at large values of ε) can be isolated. Based on this observation, the appropriate numerical strategy is to use Eqs. 6-25 and 6-26 for the explicit determination of (aε) and C, while Eq. 6-27 will serve as the non-linear root finding equation.

From Eqs. 6-25, 6-26, and 6-27, the solution set for the three simultaneous equations must solve the non-linear equation (from Eq. 6-27):

$$f(\varepsilon) = \sum_{i=1}^{n} \xi_i R_i - (a\varepsilon) \sum_{i=1}^{n} \frac{\xi_i}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)} - C \sum_{i=1}^{n} \xi_i^2 = 0 \qquad \text{(Eq. 6-28)}$$

where (from Eqs. 6-25 and 6-26):

$$a\varepsilon = \frac{1}{D}\left[\sum_{i=1}^{n} \frac{R_i}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)} \sum_{i=1}^{n} \frac{\xi_i}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)^2} - \sum_{i=1}^{n} \frac{R_i}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)^2} \sum_{i=1}^{n} \frac{\xi_i}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)}\right] \qquad \text{(Eq. 6-29)}$$

$$C = \frac{1}{D}\left[\sum_{i=1}^{n} \frac{R_i}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)^2} \sum_{i=1}^{n} \frac{1}{\lambda_i\,(\varepsilon+\lambda_i)^2} - \sum_{i=1}^{n} \frac{R_i}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)} \sum_{i=1}^{n} \frac{1}{\lambda_i(\varepsilon+\lambda_i)^3}\right] \qquad \text{(Eq. 6-30)}$$

with,

$$D \equiv \left[\sum_{i=1}^{n} \frac{1}{\lambda_i\,(\varepsilon+\lambda_i)^2} \sum_{i=1}^{n} \frac{\xi_i}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)^2} - \sum_{i=1}^{n} \frac{1}{\lambda_i\,(\varepsilon+\lambda_i)^3} \sum_{i=1}^{n} \frac{\xi_i}{\sqrt{\lambda_i}\,(\varepsilon+\lambda_i)}\right] \qquad \text{(Eq. 6-31)}$$

The solution of Eq. 6-28 is accomplished by making an initial estimate of ε and then substituting the value into Eqs. 6-29 and 6-30 to get estimates of (aε) and C. These values along with the estimate of ε are then used in Eq. 6-28 to compute f(ε). The result will generally not be zero, so standard root finding algorithms such as the "secant method" or, once the root value is bounded, the "regula falsa" (false positioning) method can be used to obtain a better estimate of ε to substitute back into Eqs. 6-29 and 6-30 to continue the root finding process. Iteration continues until either the value of f(ε) is sufficiently close to zero or

until the relative change in ε from step to step is within a user-defined tolerance band.

Figure 4-7 shows a plot of f(ε) over a range of ε values for a set of offgas, iodines and solubles samples. Note for instance from the offgas plot that f(ε) has multiple roots, which is quite typical for the solution method. Multiple roots arise because the solutions may be local minima or maxima of Eq. 6-20. The appropriate root to accept in the analysis of fuel failure predictions is the smallest ε value that results in physically realistic values of (aε) and C (i.e., the coefficients must be non-negative, since each represents a physical property). In the case of very small defects (ε << λ) it is possible that no roots of Eq. 6-28 are physically acceptable since the fundamental form of the equation assumes that ε is significant. These small defect cases must be handled in a different manner as discussed in Section 6.1.1.2.

6.1.1.2 Fuel Performance Coefficients for Very Small Defects ("Two Coefficient Fit")

Very small defects are characterized by values of ε that are negligibly small in comparison with the decay constants for all nuclides in the sample. Under this condition, the basic fuel performance coefficient fit of Eq. 6-19 takes on the simplified form of:

$$R_i = \frac{(a\varepsilon)}{\lambda_i^{3/2}} + \xi_i C \qquad \text{(Eq. 6-32)}$$

Note that Eq. 6-32 is linear with only two coefficients (aε) and C. Also, note that (aε) cannot be separated into individual components as was possible in the standard three-component non-linear fit discussed in Section 6.1.1.1. This is consistent with the assumption that ε is infinitesimally small, i.e., undefined.

Standard linear least squares fitting procedures for Eq. 6-32 may be used to obtain explicit formulations for both (aε) and C in the form:

$$a\varepsilon = \frac{1}{D}\left[\sum_{i=1}^{n}\xi_i^{\,2}\ \sum_{i=1}^{n}\frac{R_i}{\lambda_i^{\,3/2}} - \sum_{i=1}^{n}\xi_i R_i\ \sum_{i=1}^{n}\frac{\xi_i}{\lambda_i^{\,3/2}}\right] \qquad \text{(Eq. 6-33)}$$

$$C = \frac{1}{D}\left[\sum_{i=1}^{n} R_i \xi_i \quad \sum_{i=1}^{n} \frac{1}{\lambda_i^{\,3}} - \sum_{i=1}^{n} \frac{R_i}{\lambda_i^{\,3/2}} \sum_{i=1}^{n} \frac{\xi_i}{\lambda_i^{\,3/2}} \right]$$

(Eq. 6-34)

where:

$$D \equiv \sum_{i=1}^{n} \xi_1^2 \sum_{i=1}^{n} \frac{1}{\lambda_i^3} - \left[\sum_{i=1}^{n} \frac{\xi_i}{\lambda_i^{3/2}}\right]^2$$

(Eq. 6-35)

As in the case of the three-coefficient fit discussed in Section 6.1.1.1, both (aε) and C must be non-negative for the solution to be physically acceptable.

If CHIRON fails to produce a valid three-coefficient fit as described in Section 6.1.1.1, it will automatically perform a two-coefficient fit. Since the two-coefficient fit does not involve an iteration there will always be a two-coefficient solution. However, that solution will not necessarily be acceptable, because both (aε) and C must be non-negative. If the C coefficient is negative in the two-coefficient case, the sample is discarded as unusable for the fitting analysis.

Even in instances where the two coefficient fit produces valid coefficients, it should be noted that the presence of small defects invariably leads to lower overall nuclide activity levels with a corresponding decrease in the accuracy of the measurements. Thus, analyses based on two coefficient fits should be regarded as less accurate.

6.1.2 Failure Prediction by the "General Failure Models"

Section 6.1.1 describes the techniques for determining the fuel performance coefficients (aε), ε, and C, where possible, from measured coolant activity samples. Once these coefficients are determined, it is attempted to relate these coefficients to a reliable prediction of the number of failed rods, X, in the core.

The development of the basic release ratio equations for the various nuclides in a coolant activity sample, Eq. 6-19, includes the definition of the fit coefficient, a, of the form:

$$a = \sum_{k=1}^{X} \left(a'_k \; f_{Fk} \; f_{yk}\right)$$

f_{Fk} is a function of power, P, while f_{yk} is a function of burnup, B (due to the dependence of Pu ratio on rod burnup), and the value of "a" depends implicitly upon the number of failed rods, X.

Functionally, this relationship can be expressed in the general form:

$$a \approx \psi\left(X, P, B\right) \qquad \text{(Eq. 6-36)}$$

where:

a	=	The calculated fit coefficient.
X	=	Number of defective fuel rods in the core.
P	=	Power function (relating to power in defective rods).
B	=	Burnup function (relating to exposure of defective rods).
ψ	=	an unspecified functional relationship.

The assumed functional relationship of Eq. 6-36 can be rewritten:

$$X \approx \Phi\left(a\varepsilon, \varepsilon, P, B\right) \qquad \text{(Eq. 6-37)}$$

where Φ is an alternative functional relationship to be determined, and the coefficient "a" has been replaced by its constituent coefficient parts ($a\varepsilon$) and ε. If an applicable expression for Φ is known, then an estimate of the number of failed rods, X, can be made using the fit coefficients ($a\varepsilon$) and ε, along with estimates (or assumed values) of rod power and burnup.

It can be assumed that an empirical expression for Φ in which a set of coefficients are determined from existing plant data by correlating known fuel defects with measured coolant activity samples.

6.1.2.1 Fitting Method for Failure Determination

A general purpose fitting expression for Eq. 6-37 can be assumed of the form:

$$X = C_0 \left[\frac{a\varepsilon}{(\varepsilon + \varepsilon_0)} \right]^{C_1} * \exp(C_2 P) \qquad \text{(Eq. 6-38)}$$

where C_0, C_1, C_2 and ε_0 are empirical coefficients and the burnup term (or, more precisely, the difference in Pu fraction among the defective rods) has been assumed to have negligible effect on the failed rod prediction. It is appropriate to determine a unique set of empirical coefficients for each sample type (iodine or noble gas) in each reactor type since rod geometry and nuclide diffusion characteristics also influence the fuel performance coefficients.

Specific values for the empirical coefficients can be determined in the classical way by taking the logarithm of Eq. 6-38 and using a linear least squares fitting method applied to all applicable data points in the existing database. Fuel performance coefficients ($a\varepsilon$ and ε) for use in calculating the empirical coefficients are determined as described in Section 6.1.1 for each database coolant sample used in the empirical fit. The power term, P, for each plant sample data point can be expressed in the form

$$P = (RPF)_{eff} \left(\overline{LHGR}\right) \frac{P_{TOS}}{P_{RATED}} \qquad \text{(Eq. 6-39)}$$

where

$(RPF)_{eff}$ = "effective" rod power factor of all failed fuel rods relative to core average power.

$\left(\overline{LHGR}\right)$ = average rod linear heat generation rate at rated core power.

P_{TOS} = core average power at time of coolant sample.

P_{RATED} = core rated power.

The average rod linear heat generation rate in Eq. 6-39 is given by:

$$\overline{LHGR}_{(W/Cm)} = \frac{(\text{Rated Power})_{MWth} * \left(10^6{}_{W/MW}\right)}{(\text{Number Fuel Rods}) * (\text{Rod Length})} \qquad \text{(Eq. 6-40)}$$

There are various methods of combining the individual failed fuel rod powers when more than one failed rod exists in the core and they all exhibit different power levels. Several of these methods were evaluated during the CHIRON development. The method presently used in CHIRON consists of a failed rod weighting scheme that weights failed rods operating at higher power levels more highly:

$$(RPF)_{eff} = \left[\sum_{i=1}^{X} \left(RPF_i\right)^n / X \right]^{1/n} \qquad \text{(Eq. 6-41)}$$

where:

X = number of failed rods in the core.

n = 2.5 = weighting factor.

Various values of n were also evaluated. The above expression results in a relatively flat response over the range of $1 < n < 3$. The value of 2.5 was not totally arbitrary, in that previous work on power corrections have employed similar values (see for example Reference 2).

Since Eq. 6-41 requires knowledge of the number of defective rods and their respective rod powers, its use is primarily of importance when CHIRON is being used as a confirmation tool (i.e., confirming the predictive capability of the code after fuel inspections have identified specific failed rods from a previous cycle). For failure estimates made during the course of an operating cycle it is appropriate to use an estimate of $(RPF)_{eff}$. Estimates of $(RPF)_{eff}$ may be obtained from several methods such as reviewing transient cesium data, flux tilting information, or previous fuel failure experience. If no other estimate of rod power is available, a value of $(RPF)_{eff} \approx 1.08$ has been found to be typical of the failed rods used in the CHIRON failure database and is recommended for use in the absence of specific knowledge of rod powers for defective rods in the core.

6.1.2.2 The Fit Coefficients

Fits according to Eq. 6-38 have been performed for different categories within the original database: BWR offgas, BWR iodines, PWR offgas, and PWR iodines. However, it was concluded that the category PWR offgas did not contain enough

data to provide an independent fit. Therefore, the BWR offgas failure model is also applied in CHIRON to PWR offgas predictions. Thus, the following three failure models, referred to as the ***General Failure Models***, are available in CHIRON:

1) BWR and PWR, offgas

2) BWR, iodines

3) PWR, iodines

The fit coefficients (referring to Eq. 6-38) are as follows:

		BWR&PWR Offgas	BWR Iodines	PWR Iodines
C_0	=	17030.	7659.	3541.
C_1	=	0.7512	0.3849	0.5921
C_2	=	-0.006768	-0.01269	-0.0006488
ε_0	=	5.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}

Since no failure models have been specifically developed for reactor solubles, ***any requested solubles fits will be based on the iodines model for the given plant type***.

Previous investigations into the release characteristics of iodine from UO_2 in CANDU reactors have identified the need to adjust the release measurements for I-I32 for the large influences of precursors (predominantly the decay of Te-132). Since the iodine modeling data samples included all five iodine isotopes of interest (specifically I-132), it was also possible to investigate the potential influence of precursor contribution to the coolant activity measurements in light water reactors. In order to evaluate this potential effect, correlations of fuel failures were performed on model data with and without the I-132 measurement data included in the sample.

The two correlations were then compared from both the standpoints of differences in the coefficients and differences in the resulting fuel failure predictions. This comparison revealed that for BWRs and PWRs, the correlations were essentially unaffected by the removal of the I-132; thus there was no indication of an additional precursor effect for I-132 in light water reactor

coolants samples. A plausible explanation for the lack of noticeable precursor effects on CHIRON results is that the yield terms used within CHIRON are "equilibrium" values that include precursor decay contributions in the final yield term. Since removal of the I-132 from the measured sample leads to increased statistical uncertainty and since precursor contributions are implicitly included in the CHIRON equilibrium values, it is recommended that I-132 be included in the measurement samples for CHIRON evaluation.

6.1.3 Concentration to Release Rate Conversions

The conversion of measured coolant activity in volumetric concentrations (μCi/cc) to a release rate (μCi/sec) is sensitive to a number of plant-cycle configuration and operational parameters, which are not always accurately known. The purpose of this section is to explain how the internal CHIRON conversions are performed.

Recall from Eq. 6-1 that there are three "loss" terms that must be accounted for in the conversion: λ_i is the decay constant for isotope i, β is the decay constant of the cleanup / letdown system, and ϕ is the iodine loss associated with the steam flow (BWRs only). The following matrix shows the applicability of the various terms for BWR and PWR to offgas and iodine.

(X-marks denote that term is included)

		λ	β	ϕ
BWR	Offgas	—	—	—
	Iodine	X	X	X
	Rx. Sol	X	X	—
PWR	Offgas	X	X	—
	Iodine	X	X	—
	Rx. Sol	X	X	—

The following discussion describes the conversions performed by CHIRON:

Beta, if required, is computed in two steps:

$$\text{beta} = \frac{63.0903\ \text{(cc/gal)(min/sec)} * \text{Flow Rate gpm} * \text{CU Density g/cc} * \text{CUFlowFact Unitless}}{\text{Cool Mass g}} \quad \text{1/sec} \qquad \text{(Eq. 6-42)}$$

where:

CU Density ≡ Coolant density at the cleanup/letdown flow measurement point.

CUFlowFact ≡ Conversion factor used by CHIRON to convert cleanup/letdown flow input values to gal/min from user specified unit.

Flow Rate ≡ Cleanup/letdown flow rate at and before sampling.

The beta term is subsequently adjusted to account for the efficiency of the removal system. This removal efficiency is specified in CHIRON as a plant-cycle configuration parameter. The iodines (and reactor solubles) are normally removed by the cleanup system ion exchange beds for which a removal efficiency may be specified. In the case of PWR offgas the removal efficiency is normally assumed to be 100% (1.0) for the letdown system. This adjustment is performed by a simple multiplication:

$$\text{BetaOG} = \text{beta} * \textit{GasRemEff} \qquad \text{(Eq. 6-43)}$$

$$\text{BetaIOD} = \text{beta} * \textit{IodRemEff} \qquad \text{(Eq. 6-44)}$$

$$\text{BetaRXS} = \text{beta} * \textit{SolRemEff} \qquad \text{(Eq. 6-45)}$$

where:

GasRemEff	≡	PWR Gas removal efficiency for the cleanup/letdown system.
IodRemEff	≡	Iodine removal efficiency for the cleanup/letdown system.
SolRemEff	≡	Solubles removal efficiency for the cleanup/letdown system.

Offgas Conversions

If the offgas measurement is inputted as a volumetric activity concentration, a conversion must be carried out to obtain a coolant activity release rate in μCi/sec. The offgas conversion within CHIRON is reactor type dependent. The following equations show how CHIRON handles the offgas conversion.

BWR Offgas

$$\underset{\mu Ci/sec}{\text{Activity}} = \underset{\mu Ci/cc}{\textit{Input value}} * \textit{OGfact} * \underset{cc/sec}{\textit{SJAE GasFlow}} \qquad \text{(Eq. 6-46)}$$

where

Input value	≡	User input coolant sample measurement in volumetric concentration unit.
OGfact	≡	Conversion factor used in CHIRON to convert input to μCi/cc from user specified volumetric concentration unit.
SJAE GasFlow	≡	Adjusted gas flow at the Steam Jet Air Ejector (SJAE).

PWR Offgas

$$\text{Activity}_{\mu Ci/sec} = \frac{(\underset{\mu Ci/cc}{\textit{Input value}} * \textit{Ogfact}) * \underset{g}{\textit{Cool Mass}} * (\underset{1/sec}{\text{BetaOG}} + \underset{1/sec}{\lambda_i})}{\underset{1\ g/cc}{\text{Coolant Sample Density}}} \qquad \text{(Eq. 6-47)}$$

where:

Input value ≡ User input coolant sample measurement in volumetric concentration unit.

OGfact ≡ Conversion factor used by CHIRON to convert offgas input to μCi/cc from the user specified volumetric concentration unit.

λ_i ≡ Decay constant for isotope i.

and the variable BetaOG is as calculated above by Eqs. (6-42) and (6-43). Note that the coolant sample density is assumed to be equal to 1 g/cc.

Iodine Conversion

The iodine conversion within CHIRON is ***not*** reactor type dependent, with a single exception: the ϕ term, iodine carryover with the steam, is set equal to zero for PWRs. The following equations show how CHIRON handles the iodine conversion.

$$\text{Activity} = \frac{\underset{\mu Ci/Cc}{(\textit{Input value} * \textit{IODfact})} * \underset{g}{\textit{Cool Mass}} * (\underset{1/sec}{\text{BetaIOD}} + \underset{1/sec}{\lambda_i} + \underset{1/sec}{\phi})}{\underset{1\ g/cc}{\text{Coolant Sample Density}}} \qquad \text{(Eq. 6-48)}$$

$\mu Ci/sec$

where

Input value ≡ User input coolant sample measurement in volumetric concentration unit.

IODfact ≡ Conversion factor used by CHIRON to convert input to μCi/cc from user specified volumetric concentration unit.

λ_i ≡ Decay constant for isotope i.

ϕ ≡ Iodine carryover with the steam as described below ($\phi = 0$ for PWRs).

and the variable BetaIOD is as calculated by Eqs. (6-42) and (6-44).

For BWRs there is an additional loss of iodine via carryover with the steam (ϕ). The steam carryover term, ϕ, for BWRs represents a "loss", or removal, of iodine from the water in the reactor core (similar to the loss due to the cleanup system).

Computation of this term requires a user input, Θ (Theta), which is the measured iodine fractional carryover term. This value is normally in the range of 1/2 % to 2 % and is heavily dependent upon the type of condensate demineralizer cleanup system. BWRs with "Powdex" systems will frequently have carryover values near the lower end of the range. BWRs with "Deep-Bed" systems should expect to see values closer to 2 %. The carryover value, Θ, is obtained by a series of chemistry measurements beyond the scope of this document. These measurements should ideally be repeated from time to time. However, most often they are only obtained by the vendor at original plant startup. The Θ-value is normally relatively stable, but may be sensitive to other plant configuration parameters.

The ϕ term is computed as:

$$\phi \left[\frac{1}{sec}\right] = \frac{\Theta\ [Fraction] * StmFlow\ [lb/hr] * [P/Pr]\ [Fraction]}{Cool\ Mass\ [g] * 7.938\ (sec/hr)\ (lb/g)} \quad \text{(Eq. 6-49)}$$

where:

Θ ≡ Theta, the plant-specified fractional steam carryover.

StmFlow ≡ Plant Steam Flow in lbs/hr at ***rated power.***

P/Pr ≡ Reactor Fractional Power at time of sampling.

The CHIRON equation uses the constant 7.938 to account for proper unit conversion. If the plant ID or configuration specifies a PWR the ϕ term is set equal to zero.

Reactor Solubles Conversion

The reactor solubles conversion in CHIRON is not dependent on reactor type. The following equation shows how CHIRON handles the reactor solubles conversion.

$$\text{Activity}\ \left[\frac{\mu Ci}{sec}\right] = \frac{(Input\ value\ [\mu Ci/cc] * RXSfact) * Cool\ Mass\ [g] * (BetaRXS\ [1/sec] + \lambda_i\ [1/sec])}{\text{Coolant Sample Density } [1\ g/cc]} \quad \text{(Eq. 6-50)}$$

where:

Input value ≡ User input coolant sample measurement in volumetric concentration unit.

RXSfact	≡	Conversion factor used in CHIRON to convert input to μCi/cc from user specified volumetric concentration unit.
λ_i	≡	Decay constant for isotope i.

and the variable BetaRXS is as calculated above by Eqs. (6-42) and (6-45).

6.2 COMBINED FAILURE MODEL

The most significant cause of uncertainty of the General Failure Models in CHIRON is the user requirement to input the rod power factor (RPF), i.e., the ratio of the linear heat rating of the failed fuel to the core average linear heat rating. In several cases where CHIRON was unsuccessful in predicting the number of failures correctly, re-analyses were performed after experimental determination of the rod power factor of the failed rods, and these analyses proved to be considerably more accurate. Therefore, the "Combined Failure Model" was developed, which uses a special technique to estimate the RPF while the reactor is still operating, in an attempt to achieve improved failure predictions. The development of the "Combined Failure Model" is described in the following.

6.2.1 Existing Improved Method

In some cases it is possible to establish an empirical connection between certain failure modes and the characteristics of the associated coolant and offgas activities. In a study performed by Taipower (Reference 6), D. Lin reported that fretting induced failures tended to be associated with larger defect sizes and relatively low values of the activity release rate per failed rod. The latter translates into a low rod power factor for the failed fuel. Thus, the study essentially establishes an empirical relationship between the defect size parameter, ε, and the rod power factor, ***for a specific failure mode***. Since the basic CHIRON analysis normally calculates the value of ε, the subsequent failure predictions may be improved for the specific failure mode by taking advantage of the associated value of the rod power factor.

6.2.2 Improvement Development for CHIRON

Significant improvement of the CHIRON on-line failure predictions could be achieved if the rod power factor can be determined during operation from coolant and offgas activity, ***without the assumption of a particular failure mode.***

Analyses have been performed on a number of recent, well-documented cases of fuel failures in both BWRs and PWRs. These analyses, have revealed that it may be

feasible to determine the rod power factor directly from fission product activity samples. The fundamental principle that allows this determination is the fact that the ratio between the activities associated with the iodines and noble gases from the failed fuel rod(s) is temperature dependent. This temperature dependency is due to the difference in the individual temperature dependencies for iodines and noble gases with respect to the migration characteristics through the fuel rod and core system. Thus, for the method to be successful, both iodine and offgas samples of good quality must be available from within the same time interval. In this context, "good quality" means that both $a\varepsilon$ and ε can be determined by CHIRON.

6.2.3 Operating Plant Observations

A total of thirteen plant cycles (five BWR and eight PWR)were selected for which the following characteristics applied:

1. At least one failure was monitored for sufficient time to establish steady-state conditions, and no degradation (i.e., fuel particle release) was observed within that time period.

2. Dual samples (iodines and offgas) were obtained of sufficient quality to allow "three-coefficient fits" by CHIRON (i.e., the sample analyses allowed the determination of both $a\varepsilon$ and ε).

3. The actual number of failed rods could be determined from available post-cycle fuel examination data.

4. The average failed rod power factor could be estimated from core loading and power history information from the plant.

Furthermore, the plant cycles were so selected that several of them were known to have had only one failure, while a few had shown large numbers of failures.

Three of the plant cycles provided multiple data points due to a stepwise increase in the number of failed rods through the cycle and/or varying power levels of the failed fuel. In these cases, the intermediate "observed" numbers of failed rods were inferred from the CHIRON trending plots, using the General Failure Model for offgas, and proportioning the failure prediction trend to give the correct result at end-of-cycle.

The failed fuel rod power factors were estimated from core loading information and, where available, failed fuel power histories. In all cases of multiple failures, a weighted average of the failed fuel power was used, giving the highest weight to the highest powered failed rods. In cases where no specific information on the power level of the failed fuel was available; the rod power factors were set to unity.

6.2.4 Data Analysis

According to the CHIRON theory described in Section 6.1, the a-coefficient is proportional to a weighted sum of activity contributions from all the failed rods. It basically represents the diffusion rate of the radioactive nuclides through the fuel pellets and the rod free volume, and it includes the functional dependency on the fuel temperature. However, CHIRON does not specifically output the value of "a", because the calculated quantity $a\varepsilon$ is used directly in the failure models. Thus, in the present analysis the notation "a" always means "$a\varepsilon/\varepsilon$", which preserves the direct connection to the CHIRON-calculated quantities. Notably, this also implies that "a" is only available when both ε is non-zero, i.e., when the sample data allows a three-coefficient fit.

To facilitate the discussion below, the following terminology is used:

X	=	The number of failed rods in the core.
a (= $a\varepsilon/\varepsilon$)	=	The total release coefficient for a given isotopic group (iodines or noble gases).
a_n (= a/X)	=	The normalized release coefficient for a given isotopic group (iodines or noble gases).
Offgas	=	This term is used interchangeably with the term "noble gases".

Since "a" is a sum of contributions from all the failed rods, the normalized release coefficient refers to the average release rate per failed rod. Expressed individually for iodines and offgas it becomes:

$$a_{n,I} = a_I/X \qquad \text{(Eq. 6-51)}$$

$$a_{n,O} = a_O/X \qquad \text{(Eq. 6-52)}$$

where subscripts I and O refer to iodines and offgas, respectively.

Furthermore, if the dependency of the diffusion coefficient component of a_n on the failed rod heat rating (which is also considered a proportional measure of temperature) is assumed to be exponential, Eqs. 6-51 and 6-52 may be rewritten:

$$a_{n,I} = a_{n0,I} * (LHGR/LHGR_0) * \exp[c_I\,(LHGR\text{-}LHGR_0)/LHGR_0] \qquad \text{(Eq. 6-53)}$$

$$a_{n,O} = a_{n0,O} * (LHGR/LHGR_0) * \exp[c_O (LHGR-LHGR_0)/LHGR_0] \quad \text{(Eq. 6-54)}$$

where:

$a_{n0,I}$	=	the normalized release coefficient for iodines at the reference heat-rating.
$a_{n0,O}$	=	the normalized release coefficient for noble gases at the reference heat-rating.
c_I	=	coefficient for the power dependency of the diffusional iodine release rate from the fuel pellet.
c_O	=	coefficient for the power dependency of the diffusional noble gas release rate from the fuel pellet.
LHGR	=	the heat rating of the failed fuel.
$LHGR_0$	=	a reference heat-rating.

The component of a_n that shows a linear dependency of LHGR (the second factor of Eqs. 6-53 and 6-54) reflects the magnitude of the fission product generation rate.

Eqs. 6-51 through 6-54 lead to:

$$a_I/a_O = A * \exp[B * (LHGR-LHGR_0)/LHGR_0] \quad \text{(Eq. 6-55)}$$

or:

$$LHGR=LHGR_0 (1 + \ln[(a_I/a_O)/A] / B) \quad \text{(Eq. 6-56)}$$

where:

$$A = a_{n0,I}/a_{n0,O} \quad \text{(Eq. 6-57)}$$

$$B = c_I - c_O \quad \text{(Eq. 6-58)}$$

The number of failed rods may now be expressed by:

$$X = a_I/a_{n0,I} *LHGR_0/LHGR* \exp[- c_I (LHGR-LHGR_0)/LHGR_0] \quad \text{(Eq. 6-59)}$$

and:

$$X = a_O/a_{n0,O} * LHGR_0/LHGR * \exp[- c_O (LHGR-LHGR_0)/LHGR_0] \quad \text{(Eq. 6-60)}$$

It does not matter which one of these two equations is used; taking the ratio of Eqs. 6-59 and 6-60, then applying Eqs. 6-55, 6-57 and 6-58, shows that Eqs. 6-59 and 6-60 are indeed identical.

Logically, the reason for the identity of the failure predictions from the iodine and offgas equations is that the prediction in both cases is based on the ratio between the total release coefficient and the normalized release coefficient (see Eqs. 6-51 and 6-52). The failed fuel heat rating is determined in such a way that the ratio between the normalized release rates always equals the ratio of the total release rates.

The normalized release coefficients a_{n0} can be further expressed as follows:

$$a_{n0,I} = a_{n00,I} * (d_{ref}/d_{pel})^n * f_{mic} \quad \text{(Eq. 6-61)}$$

$$a_{n0,O} = a_{n00,O} * (d_{ref}/d_{pel})^n * f_{mic} \quad \text{(Eq. 6-62)}$$

where:

$a_{n00,I}$ = a reference normalized release coefficient for iodine release from a reference UO_2 pellet material at a reference pellet diameter.

$a_{n00,O}$ = a reference normalized release coefficient for noble gas release from a reference UO_2 pellet material at a reference pellet diameter.

d_{ref} = the reference pellet diameter, chosen to correspond to a BWR 9x9 design.

d_{pel} = the actual pellet diameter.

n = an empirical exponent, subject to benchmarking.

f_{mic} = a microstructure factor.

The coefficients of Eq. 6-55 were determined from the observed data, choosing the reference heat rating in such a way that the coefficient A becomes unity:

$LHGR_0$ = 8.30 kW/ft:

A = 1.0

B = 7.9631

The pellet size correction was performed by assuming that the pellet diameter ratio is inversely proportional to the number of rods lying along a face of the assembly so that:

$$d_{pel}/d_{ref} = 9/N_{lat} \quad \text{for BWRs}$$

$$d_{pel}/d_{ref} = 15/N_{lat} \quad \text{for PWRs}$$

where:

N_{lat} = a lattice parameter, defined as 8 for BWR 8x8, 17 for PWR 17x17, etc.

These correlations assume that BWR 9x9 rods are equivalent in diameter to PWR 15x15 rods. The exponent, n, of Eqs. 6-61 and 6-62 was set to 2, which gave the best data correlation.

The microstructure factor, fmic, is subject to determination by experience. It has been established in several joint international fuel testing programs (see References 7 and 8) that fuel from different vendors tends to display different fission gas release rates under similar testing conditions. Fuel from GE Nuclear or Westinghouse tends to release gaseous fission products at a considerably lower rate (at low and moderate burnup) than fuel made by several other vendors, while fuel made by KWU has shown a particularly high comparative gas release rate (Reference 7). The differences in release rates are related to the fuel microstructure produced by the UO_2 manufacturing technology specific to the various vendors. At high burnup, however, fuels of different microstructure appear to have similar release rates.

The present data suggests that the microstructure factor is about 6 for KWU fuel, while it is normally close to unity for fuel from GE Nuclear or Westinghouse, at least at low and moderate burnup. At high burnup, fuels of different microstructure appear to have similar release rates with a corresponding microstructure factor of unity. It is noteworthy that the release rate enhancement due to the microstructure in all cases of the present study appears to be the same for iodines and offgas.

The expected exponential relationships of $a\varepsilon/\varepsilon * (LHGR_0/LHGR)$, normalized and corrected to reference conditions, versus failed rod heat rating are verified by the data correlations. Using the reference linear heat rating, $LHGR_0 = 8.30$ kW/ft, the constants in Eqs. 6-59 through 6-62 were determined from the measured data to be:

$$a_{n00,I} = 1.0 \times 10^{-4}$$

$$a_{n00,O} = 1.0 \times 10^{-4}$$

c_I = 7.1668

c_O = -0.7963

Note that the coefficient c_O is negative. The release rate of the volatile fission products from a failed fuel rod is governed partly by diffusion in the fuel grains, partly by migration through grain boundaries, cracks and the fuel-cladding gap. The negative sign indicates that the release of the noble gases is limited by the latter process. This may be facilitated by the mechanical pressure reduction that follows from a temperature (power) reduction.

Eqs. 6-59 and 6-60 are used to determine the number of failed rods, based on the CHIRON-calculated values of $a\varepsilon$ and ε for iodines and offgas, after the linear heat rating of the failed rods has been determined from Eq. 6-56.

6.2.6 Demonstration of Benchmark Fit to Database

The Combined Failure Model defined in Section 6.2.5.2 was applied to the same plant cycle case data from which it was developed. The results (predicted failed fuel rod power factor and number of failed rods) are shown in Table 6-2, with comparison to the experimental values.

Table 6-2
Calculation of Rod Power Factor and Number of Failures from Model

Plant Cycle Data Point	RPF Predicted	RPF Actual	LHR Predicted kW/ft	N-Fail-Predicted	N-Fail Actual
BWR-A	1.0	1.0	6.47	1.2	1
BWR-B	0.7	0.7	4.63	0.4	1
BWR-C	1.2	1.2	7.47	0.7	1
BWR-D	1.0	1.0	6.10	1.4	2
BWR-E	0.7	0.7	4.27	1.7	2
PWR-A	0.9	0.9	5.05	4.0	3
PWR-B	1.0	1.0	5.33	1.9	1
PWR-C	0.4	0.4	2.13	9.8	9
PWR-D	0.5	0.4	2.13	33.1	35
PWR-E	0.9	1.0	2.80	0.9	1
PWR-F	0.8	0.9	4.71	7.8	7
PWR-G	1.1	1.0	3.86	19.8	26
PWR-H	1.1	1.2	3.31	70.8	64

Note that this process merely serves the purpose of checking the internal consistency of the numerical procedure, as well as illustrating the scatter inherent in the benchmarking database. A validation check against additional, independent data will be performed at a later time.

Figures 6-1 and 6-2 show the scatter of the fit to the experimental database for rod power factors and numbers of failed rods, respectively. It is noted that the number of failures is predicted well within a factor 2 for all but one of the cases. This data point was known to be a very small failure. Thus, the activity signals were small, and the measurements subject to particularly large uncertainty.

The scatter of the General Failure Models in CHIRON is such that the number of failures is predicted within a factor of two in 85 % of the cases for BWR offgas analyses at reactor relative powers higher than 80 %. For BWR iodine analyses and for PWR analyses the scatter of these failure models is greater. The models also contain significant systemic deviations for regimes not fully covered by the original benchmarking. Such regimes are, for instance, low power fretting failures and all cases for which the reactor was operating at less than 80 % rated power.

The Combined Failure Model predicts well within the same scatter band of a factor two as the General Failure Models. However, contrary to the General Failure Models, the Combined Failure Model may be expected to apply equally well to all conditions, including BWRs and PWRs, offgas and iodine analyses, and all levels of relative reactor power. The scatter band is partly due to the scatter in the input data, and partly due to crudeness of model assumptions. It can therefore not be reduced below a certain limit, defined by the state-of-the-art of the activity data collection methods, and the available opportunities for model improvement. Thus, the improvement that the Combined Failure Model represents over the General Failure Models lies largely in the generality of the approach, i.e., its ability to achieve on-line predictions within the acceptable scatter-band of a factor of two in practically all cases and under all conditions.

The new model offers the advantages of on-line failed fuel power determination and reconciliation of the predictive models based on iodines and offgas. These advantages are made available as a direct benefit from obtaining simultaneous samples of both radioactive species. Thus, a significant incentive has been identified to obtain synchronous dual sample measurements of both iodine and offgas activities, for both BWRs and PWRs.

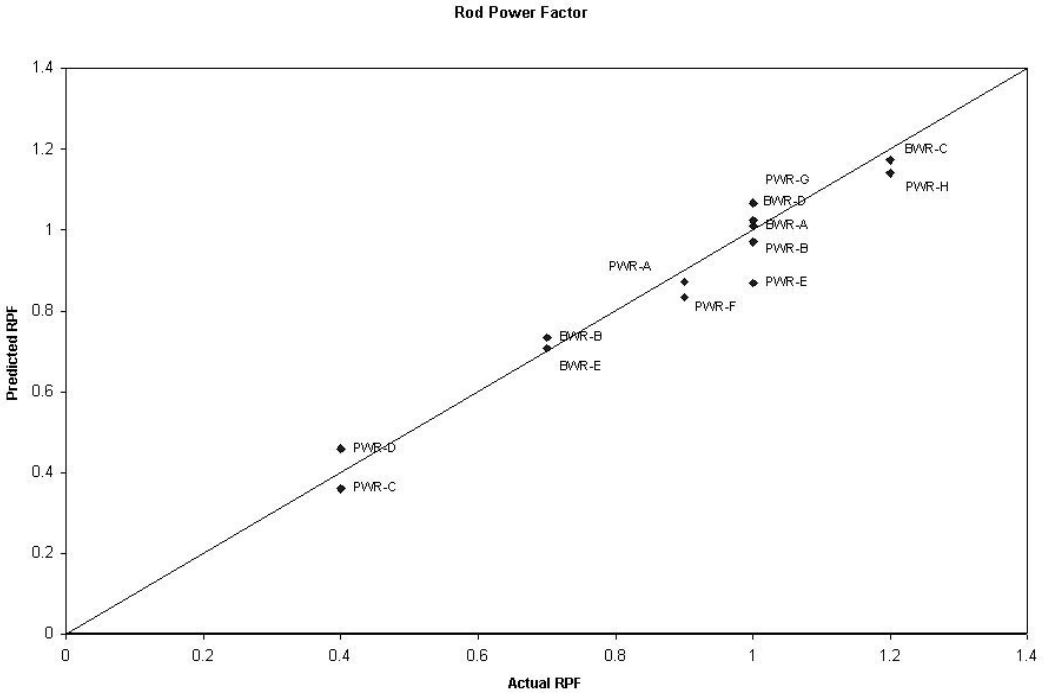

Figure 6-1
Combined Failure Model RPF Comparison

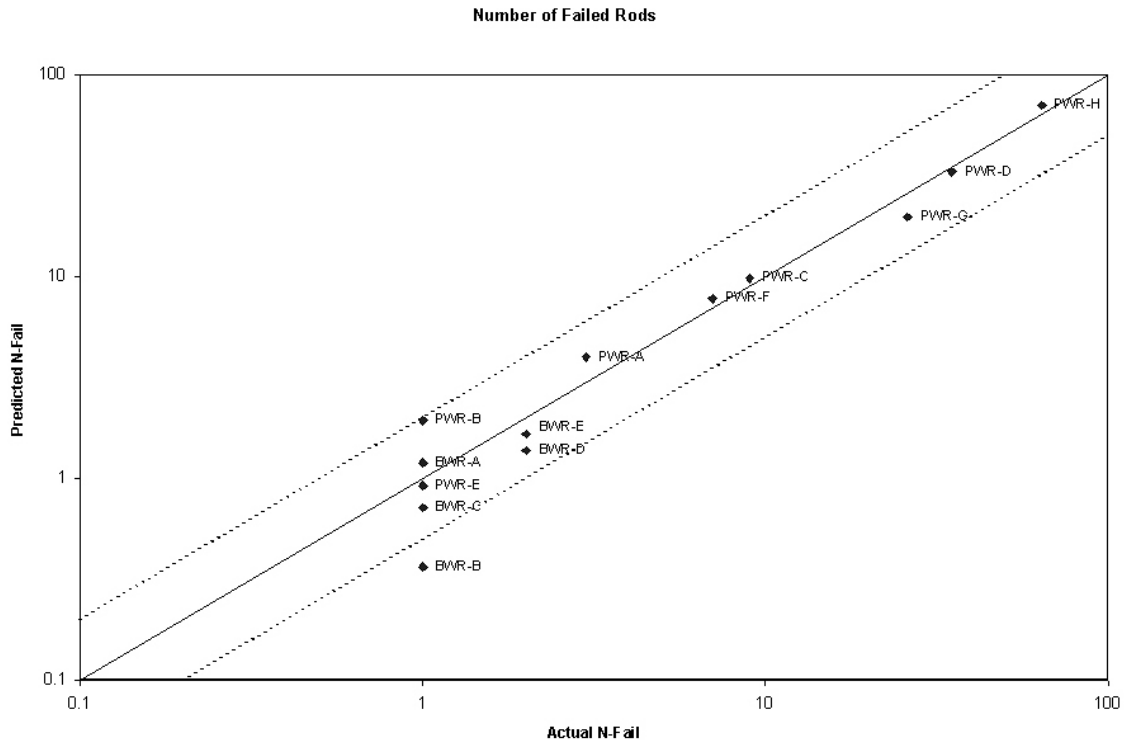

Figure 6-2
Combined Failure Model Failure Comparison

6.3 CHIRON Fuel Failure Database

An extensive fuel performance database has been accumulated for the purpose of establishing reliable fuel failure correlations for both PWR and BWR plant types. The original CHIRON fuel failure database was collected in 1984-1989, and contains approximately 2000 activity samples from BWRs and PWRs in the United States, dating from the period 1972-1988. This database was later expanded to include newer samples, mainly from PWRs with incidents of multiple failures. This expanded database, last updated in 1992, remains the basis for the General Failure Models.

The CHIRON database includes iodine and noble gas (offgas) coolant measurement results from samples covering a wide range of fuel rod operating powers. The data includes a variety of defect types (baffle jet fretting, crud-induced localized corrosion (CILC), pellet-cladding mechanical interaction (PCI), debris-induced failures, etc.) in an attempt to ensure that the resulting failure correlations would be applicable to most known defect mechanisms. Sample data in the database were systematically categorized as being applicable for use as modeling, benchmark, or low power purposes.

Modeling data was used to develop the correlation coefficients for the various correlations at near full power conditions (core power > 95%, rod power factor (RPF) > .9). These samples were selected as being consistent, reliable measurements taken during equilibrium conditions near the end of the plant's operating cycle (in order to ensure that the measurements coincided with the number of failures observed after cycle shutdown).

Benchmark data was selected as being typical of in-field measurements. These samples usually contained one or more nuclide readings that, when observed in relation to the other data, appeared to deviate somewhat from "typical" values, but whose data could not be discarded for known or suspected reasons. Comparison of these data with predictions by the correlations generated from the modeling data provided an evaluation of the validity of each correlation.

Low power data was selected on the basis of the same criteria as model data, except that the core and/or rod powers were below the model data acceptance values. These samples were used to extend the validity of the correlations into low power operating domains.

An additional database was started in 1992, to include data from entire reactor cycles, especially such cycles for which severe fuel failures have been detected or suspected. Severe fuel failures are defined as failures that involve direct release

of fuel particles from the failed rods. This work was sparked by the EPRI Severe Fuel Failures Study for BWRs (Reference 9) and, therefore, the database initially focused on BWR cycles. This database is continually expanding, and now includes a large number of PWR cycles. The development of the Combined Failure Model was based on this expanded database.

6.4 The INPO FRI

The INPO FRI has been implemented in CHIRON according to the June 1992 memorandum from INPO (Reference 2), as amended by INPO letter to EPRI of December 1992.

Accordingly, CHIRON calculates single-sample FRI-values, based on the appropriate sample group (offgas for BWRs, iodines for PWRs). At the end of a specified period, CHIRON then averages the single-sample values, accepting only samples that comply with the INPO criteria for steady state and power level. The averaged FRI value is finally groomed to meet the INPO specified minimum value for the given reactor type, and/or a maximum value indicated by the "Sum-of-Six" or "Sum-of-Five", as applicable, based on monthly averages of individual, power-corrected isotopic activities. If the selected averaging period coincides with a month, the resulting average FRI will be the value reportable to INPO.

7

DIAGNOSTICS AND ERROR CHECKING

Chiron generates error messages when a user tries to perform an illegal operation or tries to enter data that is not in the correct format or outside the acceptable range for that data entry field. A sample of a CHIRON error message is shown in Figure 7-1.

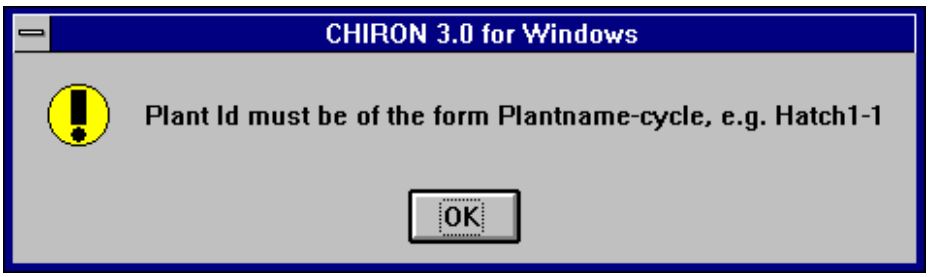

Figure 7-1
Sample CHIRON Error Message

A list of error messages that are generated by CHIRON is provided in the following subsections. The messages have been grouped into three categories: data input errors, database related errors and miscellaneous errors.

7.1 Data Input Error Messages

Data input error messages tell you what data field needs to be corrected and provides the correct format. Should you encounter a data input error message while using CHIRON, read the message carefully, write it down and then click on "OK" to return to the data entry field. Correct the data entry using the recommended format and range. Sample error messages are given below.

"Chiron cannot set its timer. Please close any open applications and retry."

"The Fit Coefficient model value was not correct"

"The Failure model value was not correct"

"Select a sample for editing"

"The following values are not within acceptable ranges: ... Please correct these values. A list of acceptable ranges can be found in the CHIRON User's Manual."

"Invalid string! Please enter another string, making sure that it has no more than 7 characters and does not contain any white spaces or illegal characters such as *, ?, /, and =. "

"Start date is earlier than date of first sample; please re-select."

"End date is later than date of last sample; please re-select."

"Start date is later than end date; please re-select."

"Cannot clear selections in SHOW SELECTED SAMPLES ONLY mode"

" The CalcDays sample number is out of range"

"The sample index is > the lastone!"

"Some negative data is on a LOG plot, the graphing is Aborted!"

"The plant is a PWR. All data in the BWR-specific block will be ignored."

"The plant type has changed. Are you sure?"

"Plant/cycle id is limited to 8 characters"

"You must select at least one cycle from the list."

"There is no sample data in the database. To enter sample data for any plant/cycle in the database, please choose Data | New. If you have not yet entered plant/cycle data, please first select Options | Plant Config | Add New Plant."

"Plant does not exist in the database. You may add a new plant from the main menu."

"This sample has been added to the database. Do you wish to add another sample?"

"The graph_index is not correct, please re-select"

"Out of range value for select_index (expected an integer from 0 to 85)"

"Error: Couldn't find plant/cycle corresponding to this sample. Aborting range-check function."

"Date format must be mm/dd/yy. Valid dates range from 01/01/70 (January 1, 1970) to 02/05/36 (February 5, 2036)."

"Time format must be hh:mm:ss in 24-hour format. For example, 4:03 p.m. and 22 seconds would be 16:03:22, and midnight would be 00:00:00."

"Plant Id must be of the form Plantname-cycle, e.g. Hatch1-1"

"The fuel type must be of the form NxN or NNxNN. Examples: 8x8 or 15x15."

"This sample will not be added to the database because at least one value is outside of its acceptable range. Please see the CHIRON User's Manual for a listing of acceptable ranges."

"An error occurred at value number %d."

"No samples were added to the database."

"Cannot delete batch because a batch is not currently selected. You may select a sample as part of a batch by double-clicking on it, or by highlighting it and pressing 'Toggle Status'. Or you may select a batch using 'Time-Select Batch'. "

"Select a sample for viewing"

"Select a sample for update"

"Cannot analyze batch because a batch is not currently selected. You may select a sample as part of a batch by double-clicking on it, or by highlighting it and pressing 'Toggle Status'. Or you may select a batch using 'Time-Select Batch'. "

"%d samples were selected, which exceeds the %d sample limit. Cannot perform trend plots."

7.2 Database Related Error Messages

Database related error messages generally mean you have performed an illegal operation. Should you encounter a database related error message while using CHIRON, read the message carefully, write it down and then click on “OK” to return to the program. Sometimes database related error messages provide a solution to the problem in the message, and sometimes they do not. If no solution is given, exit from CHIRON and then open the program again. Sample error messages are given below.

"The Selected Sample query in BATCH:pSampleSet failed!"

"The Sample queried in BATCH: doesn't match!"

"The Sample ASCII dump in BATCH: failed!"

"The Requery_Plant_Record in BATCH failed!"

"The PlantDataSet Query in BATCH failed"

"The Plant ASCII dump in BATCH: failed!"

"The RequeryRecord in BATCH:FailureSet failed!"

"Can't Update BATCH pFailureSet!"

"The AddNew_Record in BATCH:pFailureSet failed!"

"The New Edit in BATCH:pFailureSet failed!"

"The pFailureSet CanUpdate failed!"

"The pFailureSet Update failed!"

"The Update in BATCH:pFailureSet failed!"

"The Activity ASCII dump in BATCH: failed!"

The FitFailures ASCII dump in BATCH: failed!"

"Cannot open file"

"Reopened last active datasource."

"Cannot reopen current Datasource. Application will terminate."

"Database access error. Application will terminate."

"CChironCalc::unit_conversion, SampleUnits Failed"

"m_pFailureSet->Close() failed."

"m_pFailureSet->Open() failed."

"m_pFailureSet->MoveFirst() failed."

"m_pFailureSet->Edit() failed."

"m_pFailureSet->Update() failed."

"m_pFailureSet->MoveNext() failed."

"Error: Found multiple records corresponding to this sample in the failures table."

"Error while updating sample data. Changes were not accepted."

"Error on SampleSet Requery"

"This function is not available in the SHOW SELECTED SAMPLES ONLY mode"

"The highlighted sample will be permanently deleted from the database. Proceed with sample deletion?"

"Sample Deletion, bad index"

"The selected (X-marked) samples will be permanently deleted from the database. Proceed with sample deletion? "

"m_pFailureSet->Requery() failed."

"DeleteItem: The Cursor selection is invalid"

"Selection status cannot be changed in SHOW SELECTED SAMPLES ONLY mode"

"Cannot display selected samples because no samples are selected for batch analysis."

"Select a sample for analysis"

"The Selected Sample query in VIEW:pSampleSet failed!"

"The Sample queried in VIEW: doesn't match!"

"The Open_Plant_Record in VIEW:pPlantDataSet failed!"

"The PlantDataSet Query failed"

"The Open_Record in VIEW:FailureSet failed!"

"Can't Update pFailureSet!"

"The AddNew_Record in VIEW:pFailureSet failed!"

"The New Edit in VIEW:pFailureSet failed!"

"The Update in VIEW:pFailureSet failed!"

"The Open FailureRecord in TREND failed!"

"%d samples were selected, which exceeds the %d sample limit. Cannot perform batch analysis."

"The ASCII dump files already exist. Overwrite the old files?"

"The Open PlantRecord in BATCH failed!"

"The Open FailureRecord in BATCH failed!"

"FindSampleRange error"

"SetSelectListBoxItems function failed!"

"CHIRON could not launch the selected text editor. You may open the QA report file (qareport.txt) in any available editor outside of CHIRON."

"An error occurred. The QA Report was not written."

"The QA Report has been saved as 'qareport.txt'."

"PEcreate failed"

"Graph properties failed"

"Graph creation failed"

"m_pFlagFailureSet->Close() failed."

"m_pFlagFailureSet->Open() failed."

"m_pFlagFailureSet->MoveFirst() failed."

"m_pFlagFailureSet->Edit() failed."

"m_pFlagFailureSet->Update() failed."

"m_pFlagFailureSet->MoveNext() failed."

"m_pFailureSet->Requery() failed in Ctrendgraph::SelectBuffer!"

7.3 Miscellaneous Error Messages

Miscellaneous error messages generally relate to system errors. Should you encounter a miscellaneous error message while using CHIRON, read the message carefully, write it down and then click on "OK" to return to the program. You may need to exit CHIRON and restart the program. A list of miscellaneous error messages is given below.

"Calculation information: Calculated FRI is greater than sum of 6. See CHIRON User's Manual for more information." (This is an information message only. It identifies the type of calculation being used for the FRI computation. No user action is required other than clicking "OK" and continuing with CHIRON processing.)

"A memory exception occurred during Compare String processing!" (This is an internal error message indicating that memory available to the operating system is not sufficient to continue CHIRON execution. It may be necessary to exit CHIRON and reboot the computer system.)

"Memory allocation error. Application will terminate" (This is an internal error message indicating that memory available to the operating system is not sufficient to continue CHIRON execution. It may be necessary to exit CHIRON and reboot the computer system.)

"SetGraph_Properties bad m_hPE" (This is a graphical system internal error message that should not be encountered during normal CHIRON operation. If this message occurs, the user should notify CHIRON Technical Support.)

"Graphdlg:Set_Subsetpts bad graph type" (This is a graphical system internal error message that should not be encountered during normal CHIRON operation. If this message occurs, the user should notify CHIRON Technical Support.)

8

REFERENCES

1. *CHIRON - A Fuel Failure Prediction Code*. Revised User's Manual for Version 2.1, EPRI TR-102297, July 1993.

2. "Fuel Reliability," Enclosure to Memorandum from Institute for Nuclear Power Operations to Electric Power Research Institute, June 1992.

3. *An Improved Failure Model for Use in the Fuel Failure Prediction Code CHIRON*. October 1995, to be published as EPRI Report.

4. A.H. Booth, "A Suggested Method for Calculating the Diffusion of Radioactive Rare Gas Fission Products from UO_2 Fuel Elements and a Discussion of Proposed In-Reactor Experiments That May Be Used to Test Its Validity," AE-700, 1957, Atomic Energy of Canada, Ltd.

5. B.J. Lewis, "A Model for the Release of Radioactive Krypton, Xenon, and Iodine from Defective UO_2 Fuel Elements," *Nuclear Technology*, Vol. 73, April 1986.

6. David Lin, "An Improved Model for Estimating the Number and Size of Defected Fuel Rods in an Operating Reactor," ANS/IAEA Topical Meeting on Light Water Reactor Fuel Performance, April 17-21, 1994.

7. *The SUPER-RAMP Project*. Final Report, STUDSVIK-STSR-32, Studsvik Nuclear: December 1984.

8. *The Third Risø Fission Gas Release Project*. RISØ-FGP3-FINAL, Part 1, Risø National Laboratory: March 1991.

9. *Severe Degradation of BWR Fuel Failures: Coolant Activity Analysis,* EPRI TR-102799, November 1993.

A

LIST OF FILES INSTALLED BY CHIRON

Below is the listing of the files that are installed on your computer system during the CHIRON installation procedure. The location listed in the table is the default location. If you follow the installation as described in Section 2 of this manual and use the default directory, this is where the files will be placed on your system.

File Name	Version	Location	Size (Bytes)	Purpose
Ctl3dv2.dll	2.31.0.00	C:\WINDOWS\SYSTEM	27,632	ODBC File
12510866.cpx		C:\WINDOWS\SYSTEM	2,318	ODBC File
12520437.cpx		C:\WINDOWS\SYSTEM	2,151	ODBC File
12520850.cpx		C:\WINDOWS\SYSTEM	2,233	ODBC File
12520860.cpx		C:\WINDOWS\SYSTEM	2,167	ODBC File
12520861.cpx		C:\WINDOWS\SYSTEM	2,162	ODBC File
12520863.cpx		C:\WINDOWS\SYSTEM	2,173	ODBC File
12520865.cpx		C:\WINDOWS\SYSTEM	2,147	ODBC File
Cpn16ut.dll		C:\WINDOWS\SYSTEM	3,264	ODBC File
12500852.cpx		C:\WINDOWS\SYSTEM	2,320	ODBC File
Odbc16ut.dll		C:\WINDOWS\SYSTEM	5,792	ODBC File
Drvssrvr.hlp		C:\WINDOWS\SYSTEM	105,964	ODBC File

File Name	Version	Location	Size (Bytes)	Purpose
Msajt200.dll	2.50.0.1606	C:\WINDOWS\SYSTEM	995,136	ODBC File
Mscpxlt.dll	2.0.19.12	C:\WINDOWS\SYSTEM	10,304	ODBC File
Msjetdsp.dll	1.10.0.1	C:\WINDOWS\SYSTEM	85,792	ODBC File
Msjeterr.dll	2.50.0.1111	C:\WINDOWS\SYSTEM	11,232	ODBC File
Msjetint.dll	2.50.0.1111	C:\WINDOWS\SYSTEM	15,936	ODBC File
Mstx2016.dll	2.50.0.1117	C:\WINDOWS\SYSTEM	102,080	ODBC File
Msxl2016.dll	2.50.0.1117	C:\WINDOWS\SYSTEM	149,344	ODBC File
Odbc.dll	2.10.24.1	C:\WINDOWS\SYSTEM	56,240	ODBC File
Odbc.inf		C:\WINDOWS\SYSTEM	16,584	ODBC File
Dbnmp3.dll	1994.1.26.0	C:\WINDOWS\SYSTEM	10,944	ODBC File
Odbcstp.exe	2.0.20.16	C:\WINDOWS\SYSTEM	72,896	ODBC File
Odbc3216.dll		C:\WINDOWS\SYSTEM	12,288	ODBC File
Odbcadm.exe	2.10.23.9	C:\WINDOWS\SYSTEM	6,464	ODBC File
Odbccp32.dll		C:\WINDOWS\SYSTEM	5,632	ODBC File
Odbccurs.dll	2.10.23.23	C:\WINDOWS\SYSTEM	88,896	ODBC File
Odbcinst.dll	2.10.24.1	C:\WINDOWS\SYSTEM	92,576	ODBC File
Odbcjet.hlp		C:\WINDOWS\SYSTEM	113,064	ODBC File
Odbcjt16.dll	2.0.23.17	C:\WINDOWS\SYSTEM	246,928	ODBC File
Odbcjtnw.hlp		C:\WINDOWS\SYSTEM	83,833	ODBC File
Odbc32.dll		C:\WINDOWS\SYSTEM	12,800	ODBC File
Vbar2.dll	2.0.0.2420	C:\WINDOWS\SYSTEM	298,880	ODBC File

File Name	Version	Location	Size (Bytes)	Purpose
Odexl16.dll	2.0.23.1	C:\WINDOWS\SYSTEM	4,080	ODBC File
Odfox16.dll	2.0.23.1	C:\WINDOWS\SYSTEM	4,096	ODBC File
Odtext16.dll	2.0.23.1	C:\WINDOWS\SYSTEM	4,096	ODBC File
Sqlsrvr.dll	2.0.19.12	C:\WINDOWS\SYSTEM	161,392	ODBC File
Vaen2.olb	2.0.0.2430	C:\WINDOWS\SYSTEM	41,124	ODBC File
Vbajet.dll	2.0.0.2420	C:\WINDOWS\SYSTEM	1,984	ODBC File
Odbctl16.dll	1.0.23.9	C:\WINDOWS\SYSTEM	64,080	ODBC File
Ctl3d.dll	2.31.0.0	C:\WINDOWS\SYSTEM	26,768	ODBC File
Ole2prox.dll	2.2.120.122	C:\WINDOWS\SYSTEM	51,712	OLE File
Ole2.reg		C:\WINDOWS\SYSTEM	27,026	OLE File
Ole2conv.dll	2.1.0.1	C:\WINDOWS\SYSTEM	57,328	OLE File
Ole2disp.dll	2.2.3002.1	C:\WINDOWS\SYSTEM	164,832	OLE File
Ole2nls.dll	2.2.3002.1	C:\WINDOWS\SYSTEM	150,976	OLE File
Ole2.dll	2.2.120.122	C:\WINDOWS\SYSTEM	302,592	OLE File
Compobj.dll	2.2.120.123	C:\WINDOWS\SYSTEM	108,544	OLE File
Typelib.dll	2.2.3002.0	C:\WINDOWS\SYSTEM	177,216	OLE File
Storage.dll	2.2.120.120	C:\WINDOWS\SYSTEM	157,696	OLE File
Stdole.tlb		C:\WINDOWS\SYSTEM	4,304	OLE File
Mfc250.dll	2.5.3.0	C:\WINDOWS\SYSTEM	322,384	Program DLL File
Mfcd250.dll	2.5.3.0	C:\WINDOWS\SYSTEM	51,936	Program DLL File

File Name	Version	Location	Size (Bytes)	Purpose
Mfcoleui.dll	2.0.1.0	C:\WINDOWS\SYSTEM	146,976	Program DLL File
Pegraphs.dll	2.0.0.0	C:\WINDOWS\SYSTEM	612,352	Program DLL File
Pegraphs.hlp		C:\WINDOWS\SYSTEM	55.846	Program DLL File
Chiron1.exe		C:\CHIRON30	565,664	Program File
Dbconv.exe		C:\CHIRON30	32,334	Program File
Readme.txt		C:\CHIRON30	4,682	Program File
Chiblank.mdb		C:\CHIRON30	196,608	Database File
Chiron1.mdb		C:\CHIRON30	294,912	Database File
Chiron2.mdb		C:\CHIRON30	524,288	Database File
Chiron3.mdb		C:\CHIRON30	327,680	Database File
Dbcon090.csv		C:\CHIRON30	20,352	Example File
Dbcon091.csv		C:\CHIRON30	20,345	Example File
Dbcon092.csv		C:\CHIRON30	25,352	Example File
Dbcon093.csv		C:\CHIRON30	25,396	Example File
Dbcon094.csv		C:\CHIRON30	19.804	Example File
Dbcon095.csv		C:\CHIRON30	27,723	Example File
Dbcon09.txt		C:\CHIRON30	45,294	Example File
Dbqa.txt		C:\CHIRON30	2,579	Example File
Uninst.isu		C:\CHIRON30		Uninstall File
Isun16.exe	5.00.219.0	C:\WINDOWS	358,076	Uninstall Program

B

FORMAT OF "FILE READ" ASCII FILE

In order for a file to be read into CHIRON as described in the "File Read" input option (see Section 3.3.2 of this manual) it must follow the format presented in this appendix. Sample data input files created by the database conversion program DBConvert are automatically in this format. An example of such a file, File "dbcon09.txt", is included with the distribution.

If data input files need to be created independently of the database conversion program, set up the sample data in a spreadsheet, then export the spreadsheet file into an ASCII file, using the "comma-separated-values" (CSV) format option.

The File Read ASCII file format includes the following:

Comment lines are allowed anywhere, as denoted by a ***#-sign in the first column,*** *e. g.*:

```
#  File Read file: "<file name>"
#
#  ASCII File Read for CHIRON Version 3.0 for WINDOWS;  July 1996
#
#  Plant ID: DBCON; Cycle: 9
#
#  Plant, Cycle, Time, Rx Pow, CU Flow, RPF, BU, OgDelay, IoDelay, -, -, -
```

where the last comment line can be a listing of all the field headings.

Blank lines are allowed anywhere.

The following fields must be present in each line, separated by commas:

Plant-ID (five-char string)
Cycle (one or two digit integer)
Date (mm/dd/yy)
Time (hh:mm:ss)
Rx Power
CU Flow
RPF

BU
OgDelay
IoDelay
SolDelay
SJAE Flow
Xe-138
Xe-135m
Kr-87
Kr-88
Kr-85m
Xe-135
Xe-133
I-134
I-132
I-135
I-133
I-131

Tc-101
Ba-141
Cs-138
Ba-139
Sr-92
Tc-99m
Sr-91
Np-239
Mo-99
Te-132
Ba-140
Te-129m
Sr-89
Cs-134
Sr-90
Cs-137
N-13
Rb-89
Nb-97
Ar-41
Cu-64
Na-24
Zr-97
Y-90
Cr-51
Fe-59
Hf-181

Zr-95
Co-58
Zn-65
Mn-54
Co-60

All fields in this list which are not specifically type-designated, are numeric. Any numeric format may be used. Numeric fields must be written in a compacted manner, without embedded blanks (e.g. "3.879e-005", not "3.879 e -5"). However, leading and trailing blanks before or after commas are permitted.

The total length of a line must not exceed 512 characters.

The **regular boldfaced** fields are required. If some activities are not available, zeros must be entered.

The *italic boldfaced* fields are optional.

C

SAMPLE QA FILE REPORT

The sample analysis QA report provides all input and output data for the current single-sample analysis, including plant configuration data, model parameter selections, calculational options settings, model versions and model constants. This file is intended to provide a complete QA record for any single sample. For instructions on how to generate this report, see Section 4.3.8.

A sample QA file report is presented below. This report was produced using CHIRON and Notepad, a text editor supplied with Windows.

```
CHIRON for Windows QA Report for Sample Analysis.
    Electric Power Research Institute
    Filename:        qareport.txt

Plant Cycle, Date, and Time analyzed:
    plantcycle       BWR02-11
   sample date and time     08/12/95     20:30:00
   Analysis datetime        03/05/98     17:44:09

Model revisions:
   Chiron for Windows Program                        Rev 3.0        Date 03/01/98
   Combined Failure Model                            Rev 1.1        Date 10/30/95
   General Failure Model                             Rev 2.1        Date 03/15/92
   3 Coefficient Fit (2 if epsilon is small)         Rev 1.1        Date 03/01/92
   INPO FRI Calculation                              Rev 2.0        Date 12/15/92

Model settings:
    Combined Failure flag =             TRUE
    INPO_FRI_Calculation flag =         TRUE
    Perform Solubles calculation =      FALSE
    converg criter                      0.0001
    epsilon_0                           1e-006
    f_micro                             1
    loop on Pu239 fuel yld frac         TRUE
    fuel Pu239 yld frac                 0
    converg iterat                      50
    set Pu239 tramp yld frac            FALSE
    tramp Pu239 yld frac                0
    tramp recoil                        1

Sample Input Settings:
    Reactor Power          1      %P
    Cleanup Flow           200    Gal/min (*)
    Rod Power Factor       1
    Burnup                 0      MWd/kgU (*)
    Gas Delay Time         265    (sec)
    Iod Delay Time         0      (sec)
    Sol Delay Time         0      (sec)
    SJAE gas flow          7200   cc/sec (*)
```

Xe138	2777	uCi/sec (*)
Xe135M	0	uCi/sec (*)
Kr87	727	uCi/sec (*)
Kr88	731	uCi/sec (*)
Kr85M	247	uCi/sec (*)
Xe135	970	uCi/sec (*)
Xe133	520	uCi/sec (*)
I134	0.002834	uCi/cc (*)
I132	0.001027	uCi/cc (*)
I135	0.0005693	uCi/cc (*)
I133	0.0003094	uCi/cc (*)
I131	8.844e-005	uCi/cc (*)
Tc101	0	uCi/cc (*)
Ba141	0	uCi/cc (*)
Cs138	0.0009035	uCi/cc (*)
Ba139	0.0006686	uCi/cc (*)
Sr92	0.0005708	uCi/cc (*)
Tc99M	6.348e-005	uCi/cc (*)
Sr91	0.0003086	uCi/cc (*)
Np239	0	uCi/cc (*)
Mo99	0	uCi/cc (*)
Te132	0	uCi/cc (*)
Ba140	0	uCi/cc (*)
Te129M	0	uCi/cc (*)
Sr89	0	uCi/cc (*)
Cs134	4.522e-005	uCi/cc (*)
Sr90	0	uCi/cc (*)
Cs137	4.125e-005	uCi/cc (*)
N13	0	uCi/cc (*)
Rb89	0	uCi/cc (*)
Nb97	0	uCi/cc (*)
Ar41	0	uCi/cc (*)
Cu64	0	uCi/cc (*)
Na24	0	uCi/cc (*)
Zr97	0	uCi/cc (*)
Y90	0	uCi/cc (*)

```
   Cr51              0            uCi/cc (*)
   Fe59              0            uCi/cc (*)
   Hf181             0            uCi/cc (*)
   Zr95              0            uCi/cc (*)
   Co58              0            uCi/cc (*)
   Zn65              0            uCi/cc (*)
   Mn54              0            uCi/cc (*)
   Co60              0            uCi/cc (*)

Plant Input Settings:
    Rx Type                BWR
    Rated Power            2436    MW
    Rx Water Mass          1.656e+008    g
    ClnUp Flow den         1       g/cc
    Offgas Rem Eff         1
    Iodine Rem Eff         1
    Solubl Rem Eff         1
    carryover (BWR)        0.003
    steamflow (BWR)        1e+007  lbs/hr
    number rods            34720
    Number bundles         560
    rods per face          8
    Fuel Length            350.3   cm
```

```
Offgas Isotopes:
    Activity Measured and Predicted     units: uCi/sec (*)
   Xe138              meas  3445.18       pred  7211.23
   Xe135M             meas  0             pred  1250.9
   Kr87               meas  756.881       pred  681.729
   Kr88               meas  744.442       pred  654.089
   Kr85M              meas  249.829       pred  213.51
   Xe135              meas  975.413       pred  1053.16
   Xe133              meas  520.209       pred  520.02

    Release to Birth Measured and Predicted
   Xe138              meas  0.00117407    pred  0.00245749
   Xe135M             meas  0             pred  0.00246257
   Kr87               meas  0.00356714    pred  0.00321295
   Kr88               meas  0.00550602    pred  0.00483775
   Kr85M              meas  0.00803281    pred  0.00686502
   Xe135              meas  0.0117629     pred  0.0127005
   Xe133              meas  0.0859042     pred  0.085873

Iodine Isotopes:
    Activity Measured and Predicted     units: uCi/sec (*)
   I134               meas  149.531       pred  60.4012
   I132               meas  31.1703       pred  20.4492
   I135               meas  12.0916       pred  17.7368
   I133               meas  5.54763       pred  10.4631
   I131               meas  1.46479       pred  1.39089

    Release to Birth Measured and Predicted
   I134               meas  0.000152569   pred  6.16288e-005
   I132               meas  0.000147424   pred  9.6717e-005
   I135               meas  0.000111388   pred  0.000163391
   I133               meas  0.000150392   pred  0.000283646
   I131               meas  0.000864266   pred  0.000820661

Solubles Isotopes:
    Activity Measured and Predicted units: uCi/sec (*)
Solubles were not performed.

    Release to Birth Measured and Predicted
Solubles were not performed.
```

```
Isotope Ratios:
    RatioName         Activity Ratios Measured   Predicted
    I131/I133        0.264039            0.132933
    I131/I134        0.00979593          0.0230275
    I133/I134        0.0371003           0.173227
    Xe133/Xe138      0.150996            0.0721125
    I131/Xe133       0.00281578          0.00267468
    Cs134/Cs137      NA
    Sr92/Sr91        NA

Fit and General Failure Model Summary for Offgas:
    AEpsilon          1.7045e-009
    Epsilon           1.50591e-005
    C                 0.00238538
    R(squared)        0.998619
    Convg Err         5.50767e-005
    num iterat        13
    fit OK            TRUE
    U235frac          0.89603
    Pu239frac         0.10397
    Failures          3.84223

Fit and General Failure Model Summary for Iodine:
    AEpsilon          7.2868e-013
    Epsilon           0
    C                 0.000132638
    R(squared)        0.995829
    Convg Err         6.76856e-005
    num iterat        9
    fit OK            TRUE
    U235frac          0.944643
    Pu239frac         0.0553566
    Failures          2.61836

Fit and General Failure Model Summary for Solubles:
Solubles were not performed.
```

```
BWR General Failure Model Fit Coefficients Summary:
    Offgas C0 17030
    Offgas C1 0.7512
    Offgas C2 -0.006768
    Offgas C3 5e-006
    Offgas C4 0
    Offgas C5 0
    Offgas C6 0

    Iodine C0 7659
    Iodine C1 0.3849
    Iodine C2 -0.01269
    Iodine C3 1e-006
    Iodine C4 0
    Iodine C5 0
    Iodine C6 0

Combined Failure Model Summary:
    Failures          1.33933
    Est RPF           0.520907

Cesium Ratio Burnup Estimate:
    Est Burnup        28.7286MWd/kgU (*)

INPO FRI Calculation:
    Sample INPO FRI   4062.41

end of QA report file
```

D

ASCII DUMP FILES

Data may be exported from CHIRON by means of the ASCII Dump option. It generates a set of files (ten in all). These files may be read directly into common spreadsheet applications, such as Microsoft Excel. The sample ASCII Dump files displayed in the remaining pages of this appendix are named Chirond0.txt, Chirond1.txt, etc. through Chirond9.txt.

File "chirond0.txt" contains one row showing the file-name, then a blank row, then one row with column headings, then a blank row, then one row of data per plant-cycle in the batch, then a blank row, and finally a row with an end-of-file sequence.

Files "chirond1.txt" - "chirond9.txt" each contain one row showing the file-name, then a blank row, then one row with column headings, then a blank row, then one row of data per sample in the batch analysis, then a blank row, and finally a row with an end-of-file sequence.

All column headings and data items are delimited by tabs, thus making the files readily available for importing into a spreadsheet application.

D.1 ASCII Dump File "Chirond0.txt"

This file contains plant-cycle information and batch analysis model settings, in the following format:

Field 1	Plant-cycle ID
Field 2	Reactor rated power (MWth)
Field 3	Number of fuel assemblies in the core
Field 4	Active fuel length (cm)
Field 5	Water mass in core primary loop (g)
Field 6	Failed fuel type ("9x9", "16x16", etc.)
Field 7	Cleanup/letdown flow density (g/cc)
Field 8	OG removal efficiency

Field 9 IO removal efficiency
Field 10 Solubles removal efficiency
Field 11 Iodines carry-over fraction
Field 12 Steam flow (lbs/hr)
Field 13 Reactor type (0 for BWR, 1 for PWR)
Field 14 Least squares fit convergence limit
Field 15 Pu^{239} fission yield ratio to use when Field 18 is 0.
Field 16 Epsilon_0 (default epsilon for Combined Failure Model)
Field 17 f_micro (fuel microstructure descriptor, 1 for "normal", >1 for AUC type)
Field 18 Fission yield (Pu^{239} fission yield ratio) loop flag (1 for loop, 0 for no loop)
Field 19 Maximum number of iteration loops
Field 20 Total number of fuel rods in the core
Field 21 Number of rods per face in fuel rod lattice of failed fuel assembly
Field 22 Flag to set the Pu^{239} yield ratio for tramp equal to value for fuel (0 = set to fuel value, 1 = use value from Field 23)
Field 23 Pu^{239} yield ratio for tramp, when not set equal to value for fuel
Field 24 Fraction of tramp that emits fission products as direct recoil

D.2 ASCII Dump File "Chirond1.txt"

This file contains sample-specific operational data, in the following format:

Field 1 Plant-cycle ID
Field 2 Sample date
Field 3 Sample time
Field 4 Reactor relative power at sample time
Field 5 Rod power factor for failed fuel (inputted value)
Field 6 Cleanup/letdown flow (gal/min)
Field 7 Offgas delay time (seconds)
Field 8 Iodines delay time (seconds)
Field 9 Solubles delay time (seconds)
Field 10 SJAE gas flow (cc/second)
Field 11 Failed fuel burnup (MWd/kgU, from inputted value)

D.3 ASCII Dump File "Chirond2.txt"

This file contains measured sample data for offgas and iodines, in the following format:

Field 1	Plant-cycle ID
Field 2	Sample date
Field 3	Sample time
Field 4	Xe-138 (as-measured, input units)
Field 5	Xe-135m (as-measured, input units)
Field 6	Kr-87 (as-measured, input units)
Field 7	Kr-88 (as-measured, input units)
Field 8	Kr-85m (as-measured, input units)
Field 9	Xe-135 (as-measured, input units)
Field 10	Xe-133 (as-measured, input units)
Field 11	I-134 (as-measured, input units)
Field 12	I-132 (as-measured, input units)
Field 13	I-135 (as-measured, input units)
Field 14	I-133 (as-measured, input units)
Field 15	I-131 (as-measured, input units)

D.4 ASCII Dump File "Chirond3.txt"

This file contains measured sample data for reactor solubles, in the following format:

Field 1	Plant-cycle ID
Field 2	Sample date
Field 3	Sample time
Field 4	Tc-101 (as-measured, input units)
Field 5	Ba-141 (as-measured, input units)
Field 6	Cs-138 (as-measured, input units)
Field 7	Ba-139 (as-measured, input units)
Field 8	Sr-92 (as-measured, input units)
Field 9	Tc-99m (as-measured, input units)
Field 10	Sr-91 (as-measured, input units)
Field 11	Np-239 (as-measured, input units)
Field 12	Mo-99 (as-measured, input units)
Field 13	Te-132 (as-measured, input units)
Field 14	Ba-140 (as-measured, input units)

Field 15 Te-129m (as-measured, input units)
Field 16 Sr-89 (as-measured, input units)
Field 17 Cs-134 (as-measured, input units)
Field 18 Sr-90 (as-measured, input units)
Field 19 Cs-137 (as-measured, input units)
Field 20 N-13 (as-measured, input units)
Field 21 Rb-89 (as-measured, input units)
Field 22 Nb-97 (as-measured, input units)
Field 23 Ar-41 (as-measured, input units)
Field 24 Cu-64 (as-measured, input units)
Field 25 Na-24 (as-measured, input units)
Field 26 Zr-97 (as-measured, input units)
Field 27 Y-90 (as-measured, input units)
Field 28 Cr-51 (as-measured, input units)
Field 29 Fe-59 (as-measured, input units)
Field 30 Hf-181 (as-measured, input units)
Field 31 Zr-95 (as-measured, input units)
Field 32 Co-58 (as-measured, input units)
Field 33 Zn-65 (as-measured, input units)
Field 34 Mn-54 (as-measured, input units)
Field 35 Co-60 (as-measured, input units)

D.5 ASCII Dump File "Chirond4.txt"

This file contains release-rate converted, measured sample data for offgas and iodines, in the following format:

Field 1 Plant-cycle ID
Field 2 Sample date
Field 3 Sample time
Field 4 Xe-138 (non-fitted, release-rate converted, cardinal units)
Field 5 Xe-135m (non-fitted, release-rate converted, cardinal units)
Field 6 Kr-87 (non-fitted, release-rate converted, cardinal units)
Field 7 Kr-88 (non-fitted, release-rate converted, cardinal units)
Field 8 Kr-85m (non-fitted, release-rate converted, cardinal units)
Field 9 Xe-135 (non-fitted, release-rate converted, cardinal units)
Field 10 Xe-133 (non-fitted, release-rate converted, cardinal units)
Field 11 I-134 (non-fitted, release-rate converted, cardinal units)
Field 12 I-132 (non-fitted, release-rate converted, cardinal units)
Field 13 I-135 (non-fitted, release-rate converted, cardinal units)

Field 14 I-133 (non-fitted, release-rate converted, cardinal units)
Field 15 I-131 (non-fitted, release-rate converted, cardinal units)
Field 16 Sum-of-Six OG (non-fitted, release-rate converted, cardinal units)
Field 17 Sum-of-Five IO (non-fitted, release-rate converted, cardinal units)
Field 18 Xe-138 (N-13 correlation, non-fitted, release-rate converted, cardinal units)
Field 19 Xe-135m (N-13 correlation, non-fitted, release-rate converted, cardinal units)
Field 20 Kr-87 (N-13 correlation, non-fitted, release-rate converted, cardinal units)
Field 21 Kr-88 (N-13 correlation, non-fitted, release-rate converted, cardinal units)
Field 22 Kr-85m (N-13 correlation, non-fitted, release-rate converted, cardinal units)
Field 23 Xe-135 (N-13 correlation, non-fitted, release-rate converted, cardinal units)
Field 24 Xe-133 (N-13 correlation, non-fitted, release-rate converted, cardinal units)
Field 25 Sum-of-Six OG (N-13 correlation, non-fitted, release-rate conv., cardinal units)

D.6 ASCII Dump File "Chirond5.txt"

This file contains release-rate converted, measured sample data for reactor solubles, in the following format:

Field 1 Plant-cycle ID
Field 2 Sample date
Field 3 Sample time
Field 4 Tc-101 (non-fitted, release-rate converted, cardinal units)
Field 5 Ba-141 (non-fitted, release-rate converted, cardinal units)
Field 6 Cs-138 (non-fitted, release-rate converted, cardinal units)
Field 7 Ba-139 (non-fitted, release-rate converted, cardinal units)
Field 8 Sr-92 (non-fitted, release-rate converted, cardinal units)
Field 9 Tc-99m (non-fitted, release-rate converted, cardinal units)
Field 10 Sr-91 (non-fitted, release-rate converted, cardinal units)
Field 11 Np-239 (non-fitted, release-rate converted, cardinal units)
Field 12 Mo-99 (non-fitted, release-rate converted, cardinal units)
Field 13 Te-132 (non-fitted, release-rate converted, cardinal units)
Field 14 Ba-140 (non-fitted, release-rate converted, cardinal units)
Field 15 Te-129m (non-fitted, release-rate converted, cardinal units)

Field 16 Sr-89 (non-fitted, release-rate converted, cardinal units)
Field 17 Cs-134 (non-fitted, release-rate converted, cardinal units)
Field 18 Sr-90 (non-fitted, release-rate converted, cardinal units)
Field 19 Cs-137 (non-fitted, release-rate converted, cardinal units)
Field 20 Sum-of-15 Sol (non-fitted, release-rate converted, cardinal units)
Field 21 N-13 (non-fitted, release-rate converted, cardinal units)
Field 22 Rb-89 (non-fitted, release-rate converted, cardinal units)
Field 23 Nb-97 (non-fitted, release-rate converted, cardinal units)
Field 24 Ar-41 (non-fitted, release-rate converted, cardinal units)
Field 25 Cu-64 (non-fitted, release-rate converted, cardinal units)
Field 26 Na-24 (non-fitted, release-rate converted, cardinal units)
Field 27 Zr-97 (non-fitted, release-rate converted, cardinal units)
Field 28 Y-90 (non-fitted, release-rate converted, cardinal units)
Field 29 Cr-51 (non-fitted, release-rate converted, cardinal units)
Field 30 Fe-59 (non-fitted, release-rate converted, cardinal units)
Field 31 Hf-181 (non-fitted, release-rate converted, cardinal units)
Field 32 Zr-95 (non-fitted, release-rate converted, cardinal units)
Field 33 Co-58 (non-fitted, release-rate converted, cardinal units)
Field 34 Zn-65 (non-fitted, release-rate converted, cardinal units)
Field 35 Mn-54 (non-fitted, release-rate converted, cardinal units)
Field 36 Co-60 (non-fitted, release-rate converted, cardinal units)

D.7 ASCII Dump File “Chirond6.txt”

This file contains fitted sample data for offgas (in release-rate units), in the following format:

Field 1 Plant-cycle ID
Field 2 Sample date
Field 3 Sample time
Field 4 Xe-138 (fitted, release-rate converted, cardinal units)
Field 5 Xe-135m (fitted, release-rate converted, cardinal units)
Field 6 Kr-87 (fitted, release-rate converted, cardinal units)
Field 7 Kr-88 (fitted, release-rate converted, cardinal units)
Field 8 Kr-85m (fitted, release-rate converted, cardinal units)
Field 9 Xe-135 (fitted, release-rate converted, cardinal units)
Field 10 Xe-133 (fitted, release-rate converted, cardinal units)
Field 11 Number of failed rods from OG General Failure Model
Field 12 Coefficient • from OG fit
Field 13 Coefficient A• from OG fit

Field 14 Coefficient C from OG fit
Field 15 Fit error (R^2) from OG fit
Field 16 Pu-239 fission yield ratio from OG fit
Field 17 Sum-of-Six OG (fitted, release-rate converted, cardinal units)
Field 18 Sum-of-Six OG for tramp (fitted, release-rate converted, cardinal units)
Field 19 Xe-138 (predicted, fitted, release-rate converted, cardinal units)
Field 20 Xe-135m (predicted, fitted, release-rate converted, cardinal units)
Field 21 Kr-87 (predicted, fitted, release-rate converted, cardinal units)
Field 22 Kr-88 (predicted, fitted, release-rate converted, cardinal units)
Field 23 Kr-85m (predicted, fitted, release-rate converted, cardinal units)
Field 24 Xe-135 (predicted, fitted, release-rate converted, cardinal units)
Field 25 Xe-133 (predicted, fitted, release-rate converted, cardinal units)
Field 26 Number of failed rods from OG General Failure Model, predicted
Field 27 Coefficient • from OG fit, predicted
Field 28 Coefficient A• from OG fit, predicted
Field 29 Coefficient C from OG fit, predicted
Field 30 Fit error (R^2) from OG fit, predicted
Field 31 Pu-239 fission yield ratio from OG fit, predicted
Field 32 Sum-of-Six OG (predicted, fitted, release-rate converted, cardinal units)
Field 33 Sum-of-Six OG, tramp (predicted, fitted, release-rate converted, cardinal units)
Field 34 Calculated burnup from OG fuel release correction

D.8 ASCII Dump File "Chirond7.txt"

This file contains fitted sample data for iodines (in release-rate units), in the following format:

Field 1 Plant-cycle ID
Field 2 Sample date
Field 3 Sample time
Field 4 I-134 (fitted, release-rate converted, cardinal units)
Field 5 I-132 (fitted, release-rate converted, cardinal units)
Field 6 I-135 (fitted, release-rate converted, cardinal units)
Field 7 I-133 (fitted, release-rate converted, cardinal units)
Field 8 I-131 (fitted, release-rate converted, cardinal units)
Field 9 Number of failed rods from IO General Failure Model
Field 10 Coefficient • from IO fit

Field 11 Coefficient A• from IO fit
Field 12 Coefficient C from IO fit
Field 13 Fit error (R^2) from IO fit
Field 14 Pu-239 fission yield ratio from IO fit
Field 15 Sum-of-Five IO (fitted, release-rate converted, cardinal units)
Field 16 Sum-of-Five IO for tramp (fitted, release-rate converted, cardinal units)
Field 17 I-134 (predicted, fitted, release-rate converted, cardinal units)
Field 18 I-132 (predicted, fitted, release-rate converted, cardinal units)
Field 19 I-135 (predicted, fitted, release-rate converted, cardinal units)
Field 20 I-133 (predicted, fitted, release-rate converted, cardinal units)
Field 21 I-131 (predicted, fitted, release-rate converted, cardinal units)
Field 22 Number of failed rods from IO General Failure Model
Field 23 Coefficient • from IO fit
Field 24 Coefficient A• from IO fit
Field 25 Coefficient C from IO fit
Field 26 Fit error (R^2) from IO fit
Field 27 Pu-239 fission yield ratio from IO fit
Field 28 Sum-of-Five IO (predicted, fitted, release-rate converted, cardinal units)
Field 29 Sum-of-Five IO, tramp (predicted, fitted, release-rate converted, cardinal units)
Field 30 Calculated burnup from IO fuel release correction

D.9 ASCII Dump File "Chirond8.txt"

This file contains fitted sample data for reactor solubles (in release-rate units), in the following format:

Field 1 Plant-cycle ID
Field 2 Sample date
Field 3 Sample time
Field 4 Tc-101 (fitted, release-rate converted, cardinal units)
Field 5 Ba-141 (fitted, release-rate converted, cardinal units)
Field 6 Cs-138 (fitted, release-rate converted, cardinal units)
Field 7 Ba-139 (fitted, release-rate converted, cardinal units)
Field 8 Sr-92 (fitted, release-rate converted, cardinal units)
Field 9 Tc-99m (fitted, release-rate converted, cardinal units)
Field 10 Sr-91 (fitted, release-rate converted, cardinal units)
Field 11 Mo-99 (fitted, release-rate converted, cardinal units)

Field 12 Te-132 (fitted, release-rate converted, cardinal units)
Field 13 Ba-140 (fitted, release-rate converted, cardinal units)
Field 14 Te-129m (fitted, release-rate converted, cardinal units)
Field 15 Sr-89 (fitted, release-rate converted, cardinal units)
Field 16 Cs-134 (fitted, release-rate converted, cardinal units)
Field 17 Sr-90 (fitted, release-rate converted, cardinal units)
Field 18 Cs-137 (fitted, release-rate converted, cardinal units)
Field 19 Number of failed rods from IO General Failure Model
Field 20 Coefficient • from Solubles fit
Field 21 Coefficient A• from Solubles fit
Field 22 Coefficient C from Solubles fit
Field 23 Fit error (R^2) from Solubles fit
Field 24 Sum-of-15 Solubles (fitted, release-rate converted, cardinal units)
Field 25 Sum-of-15 Solubles, tramp (fitted, release-rate converted, cardinal units)
Field 26 Delta Zr-95 attributable to cladding-spacer fretting
Field 27 Cladding damage calculated from Zr-95

D.10 ASCII Dump File "Chirond9.txt"

This file contains calculated numbers of failures, INPO FRI, and Calculated Burnup from the Cs-Ratio, in the following format:

Field 1 Plant-cycle ID
Field 2 Sample date
Field 3 Sample time
Field 4 Number of failures from Combined Failure Model
Field 5 Rod power factor calculated from Combined Failure Model
Field 6 INPO FRI ("Sample Value") for appropriate Plant Type
Field 7 BU determined from Cs-Ratio (MWd/kgU) (-1 if not determined)

E

CHIRON DATABASE FORMAT

This Appendix contains six tables that show the format of the data tables in the CHIRON database. The six data tables in the CHIRON database include: plant_data, samples, unit_types, units, user_preferences, and failures. The column name, data type and size of each entry in the CHIRON database are provided in the tables.

Table E-1
Plant Data Table (plant_data)

Column Name	Data Type	Size
plantcycle_id	Text	8 characters
plant_type	Number (Integer)	2 bytes
rated_power	Number (Single)	4 bytes
num_bundles	Number (Single)	4 bytes
num_rods	Number (Single)	4 bytes
rods_per_face	Number (Single)	4 bytes
fuel_length	Number (Single)	4 bytes
rx_water mass	Number (Single)	4 bytes
fuel_type	Text	50 characters
clnup_ltdwn_flow	Number (Single)	4 bytes
I_removal_eff	Number (Single)	4 bytes
OG_removal_eff	Number (Single)	4 bytes
sol_removal_eff	Number (Single)	4 bytes
carryover	Number (Single)	4 bytes
steam_flow	Number (Single)	4 bytes
fission_yield_flag	Yes/No	1 byte
default_pu239_yield	Number (Single)	4 bytes
tramp_flag	Yes/No	1 byte
tramp_pu239_fraction	Number (Single)	4 bytes
tramp_recoil_release	Number (Single)	4 bytes
convergence_criteria	Number (Single)	4 bytes
maxloop	Number (Long)	4 bytes
epsilon_0	Number (Single)	4 bytes
f_micro	Number (Single)	4 bytes
solubles_calculation	Yes/No	1 byte

Table E-2
Sample Data Table (samples)

Column Name	Data Type	Size
sample_datetime	Date/Time	8 bytes
rx_power	Number (Single)	4 bytes
cleanup_flow	Number (Single)	4 bytes
gas_delay_time	Number (Single)	4 bytes
iodine_delay_time	Number (Single)	4 bytes
solubles_delay_time	Number (Single)	4 bytes
sjae_gasflow	Number (Single)	4 bytes
Xe-138	Number (Single)	4 bytes
Xe-135M	Number (Single)	4 bytes
Kr-87	Number (Single)	4 bytes
Kr-88	Number (Single)	4 bytes
Kr-85m	Number (Single)	4 bytes
Xe-135	Number (Single)	4 bytes
Xe-133	Number (Single)	4 bytes
I-134	Number (Single)	4 bytes
I-132	Number (Single)	4 bytes
I-135	Number (Single)	4 bytes
I-133	Number (Single)	4 bytes
I-131	Number (Single)	4 bytes
plant_id	Text	50 characters
cycle_id	Number (Integer)	2 bytes
rod_powfact	Number (Single)	4 bytes
burnup	Number (Single)	4 bytes
rxpower_units	Number (Integer)	2 bytes
clnup_units	Number (Integer)	2 bytes
offgas_units	Number (Integer)	2 bytes
iodine_units	Number (Integer)	2 bytes
burnup_units	Number (Integer)	2 bytes
solubles_units	Number (Integer)	2 bytes
sjae_units	Number (Integer)	2 bytes
Tc-101	Number (Single)	4 bytes
Ba-141	Number (Single)	4 bytes
Cs-138	Number (Single)	4 bytes
Ba-139	Number (Single)	4 bytes
Sr-92	Number (Single)	4 bytes
Tc-99M	Number (Single)	4 bytes
Sr-91	Number (Single)	4 bytes
Np-239	Number (Single)	4 bytes

Column Name	Data Type	Size
Mo-99	Number (Single)	4 bytes
Te-132	Number (Single)	4 bytes
Ba-140	Number (Single)	4 bytes
Te-129M	Number (Single)	4 bytes
Sr-89	Number (Single)	4 bytes
Cs-134	Number (Single)	4 bytes
Sr-90	Number (Single)	4 bytes
Cs-137	Number (Single)	4 bytes
N-13	Number (Single)	4 bytes
Rb-89	Number (Single)	4 bytes
Nb-97	Number (Single)	4 bytes
Ar-41	Number (Single)	4 bytes
Cu-64	Number (Single)	4 bytes
Na-24	Number (Single)	4 bytes
Zr-97	Number (Single)	4 bytes
Y-90	Number (Single)	4 bytes
Cr-51	Number (Single)	4 bytes
Fe-59	Number (Single)	4 bytes
Hf-181	Number (Single)	4 bytes
Zr-95	Number (Single)	4 bytes
Co-58	Number (Single)	4 bytes
Zn-65	Number (Single)	4 bytes
Mn-54	Number (Single)	4 bytes
Co-60	Number (Single)	4 bytes

Table E-3
Unit Types Data Table (unit_types)

Column Name	Data Type	Size
unit_id	Number (Integer)	2 bytes
isa	Number (Integer)	2 bytes

Table E-4
Units Data Table (units)

Column Name	Data Type	Size
unit_id	Number (Integer)	2 bytes
unit_String	Text	50 characters
unit_conversion	Number (Integer)	2 bytes
unit_NotReleaseRate	Yes/No	1 byte

Table E-5
User Preferences Data Table (user_preferences)

Column Name	Data Type	Size
user_id	Number (Integer)	2 bytes
offgas_units	Number (Integer)	2 bytes
iodine_units	Number (Integer)	2 bytes
burnup_units	Number (Integer)	2 bytes
cleanup_units	Number (Integer)	2 bytes
power_units	Number (Integer)	2 bytes
solubles_units	Number (Integer)	2 bytes
sjae_units	Number (Integer)	2 bytes

Table E-6
Failures Data Table (failures)

Column Name	Data Type	Size
sample_datetime	Date/Time	8 bytes
plant_id	Text	9 characters
is_record_valid	Yes/No	1 byte
OG_AEpsilon	Number (Single)	4 bytes
OG_Epsilon	Number (Single)	4 bytes
OG_C	Number (Single)	4 bytes
OG_FitError	Number (Single)	4 bytes
OG_ISConverged	Yes/No	1 byte
OG_Convergence	Number (Single)	4 bytes
OG_Iterations	Number (Integer)	2 bytes
OG_PuFraction	Number (Single)	4 bytes
OG_Failures	Number (Single)	4 bytes
I_AEpsilon	Number (Single)	4 bytes
I_Epsilon	Number (Single)	4 bytes
I_C	Number (Single)	4 bytes
I_FitError	Number (Single)	4 bytes
I_ISConverged	Yes/No	1 byte
I_Convergence	Number (Single)	4 bytes
I_Iterations	Number (Integer)	2 bytes
I_PuFraction	Number (Single)	4 bytes
I_Failures	Number (Single)	4 bytes
S_AEpsilon	Number (Single)	4 bytes
S_Epsilon	Number (Single)	4 bytes
S_C	Number (Single)	4 bytes
S_FitError	Number (Single)	4 bytes
S_ISConverged	Yes/No	1 byte
S_Convergence	Number (Single)	4 bytes
S_Iterations	Number (Integer)	2 bytes
S_PuFraction	Number (Single)	4 bytes
S_Failures	Number (Single)	4 bytes
CombinedFailures	Number (Single)	4 bytes
CalculatedRPF	Number (Single)	4 bytes
INPO_FRI	Number (Single)	4 bytes
CalculatedBU	Number (Single)	4 bytes
FuelReleaseDetected	Yes/No	1 byte
FuelReleaseRate	Number (Single)	4 bytes
Xe138_Activity	Number (Single)	4 bytes
Xe135m_Activity	Number (Single)	4 bytes
Kr87_Activity	Number (Single)	4 bytes

Column Name	Data Type	Size
Kr88_Activity	Number (Single)	4 bytes
Kr85m_Activity	Number (Single)	4 bytes
Xe135_Activity	Number (Single)	4 bytes
Xe133_Activity	Number (Single)	4 bytes
I134_Activity	Number (Single)	4 bytes
I132_Activity	Number (Single)	4 bytes
I135_Activity	Number (Single)	4 bytes
I133_Activity	Number (Single)	4 bytes
I131_Activity	Number (Single)	4 bytes
OG_Sum6	Number (Single)	4 bytes
I_Sum5	Number (Single)	4 bytes
Xe138_Activity_N13	Number (Single)	4 bytes
Xe135m_Activity_N13	Number (Single)	4 bytes
Kr87_Activity_N13	Number (Single)	4 bytes
Kr88_Activity_N13	Number (Single)	4 bytes
Kr85m_Activity_N13	Number (Single)	4 bytes
Xe135_Activity_N13	Number (Single)	4 bytes
Xe133_Activity_N13	Number (Single)	4 bytes
OG_Sum6_N13	Number (Single)	4 bytes
Tc101_Activity	Number (Single)	4 bytes
Ba141_Activity	Number (Single)	4 bytes
CS138_Activity	Number (Single)	4 bytes
Ba139_Activity	Number (Single)	4 bytes
Sr92_Activity	Number (Single)	4 bytes
Tc99_Activity	Number (Single)	4 bytes
Sr91_Activity	Number (Single)	4 bytes
Np239_Activity	Number (Single)	4 bytes
Mo99_Activity	Number (Single)	4 bytes
Te132_Activity	Number (Single)	4 bytes
Ba140_Activity	Number (Single)	4 bytes
Te129m_Activity	Number (Single)	4 bytes
Sr89_Activity	Number (Single)	4 bytes
Cs134_Activity	Number (Single)	4 bytes
Sr90_Activity	Number (Single)	4 bytes
Cs137_Activity	Number (Single)	4 bytes
Sol_Sum15	Number (Single)	4 bytes
N13_Activity	Number (Single)	4 bytes
Rb89_Activity	Number (Single)	4 bytes
Nb97_Activity	Number (Single)	4 bytes
Ar41_Activity	Number (Single)	4 bytes
Cu64_Activity	Number (Single)	4 bytes

Column Name	Data Type	Size
Na24_Activity	Number (Single)	4 bytes
Zr97_Activity	Number (Single)	4 bytes
Y90_Activity	Number (Single)	4 bytes
Cr51_Activity	Number (Single)	4 bytes
Fe59_Activity	Number (Single)	4 bytes
Hf181_Activity	Number (Single)	4 bytes
Zr95_Activity	Number (Single)	4 bytes
Co58_Activity	Number (Single)	4 bytes
Zn65_Activity	Number (Single)	4 bytes
Mn54_Activity	Number (Single)	4 bytes
Co60_Activity	Number (Single)	4 bytes
Xe138_PredAct	Number (Single)	4 bytes
Xe135m_PredAct	Number (Single)	4 bytes
Kr87_PredAct	Number (Single)	4 bytes
Kr88_PredAct	Number (Single)	4 bytes
Kr85m_PredAct	Number (Single)	4 bytes
Xe135_PredAct	Number (Single)	4 bytes
Xe133_PredAct	Number (Single)	4 bytes
OG_Sum6_fitted	Number (Single)	4 bytes
OG_Sum6_tramp_fitted	Number (Single)	4 bytes
Xe138_PredAct_FRC	Number (Single)	4 bytes
Xe135m_PredAct_FRC	Number (Single)	4 bytes
Kr87_PredAct_FRC	Number (Single)	4 bytes
Kr88_PredAct_FRC	Number (Single)	4 bytes
Kr85m_PredAct_FRC	Number (Single)	4 bytes
Xe135_PredAct_FRC	Number (Single)	4 bytes
Xe133_PredAct_FRC	Number (Single)	4 bytes
OG_Failures_FRC	Number (Single)	4 bytes
OG_Epsilon_FRC	Number (Single)	4 bytes
OG_AEpsilon_FRC	Number (Single)	4 bytes
OG_C_FRC	Number (Single)	4 bytes
OG_FitError_FRC	Number (Single)	4 bytes
OG_PuFraction_FRC	Number (Single)	4 bytes
OG_Sum6_fitted_FRC	Number (Single)	4 bytes
OG_Sum6_tramp_fitted_FRC	Number (Single)	4 bytes
OG_CalculatedBU_FRC	Number (Single)	4 bytes
I134_PredAct	Number (Single)	4 bytes
I132_PredAct	Number (Single)	4 bytes
I135_PredAct	Number (Single)	4 bytes
I133_PredAct	Number (Single)	4 bytes
I131_PredAct	Number (Single)	4 bytes

Column Name	Data Type	Size
I_Sum5_fitted	Number (Single)	4 bytes
I_Sum5_tramp_fitted	Number (Single)	4 bytes
I134_PredAct	Number (Single)	4 bytes
I132_PredAct	Number (Single)	4 bytes
I135_PredAct	Number (Single)	4 bytes
I133_PredAct	Number (Single)	4 bytes
I131_PredAct	Number (Single)	4 bytes
I_Failures_FRC	Number (Single)	4 bytes
I_Epsilon_FRC	Number (Single)	4 bytes
I_AEpsilon_FRC	Number (Single)	4 bytes
I_C_FRC	Number (Single)	4 bytes
I_FitError_FRC	Number (Single)	4 bytes
I_PuFraction_FRC	Number (Single)	4 bytes
I_Sum5_fitted_FRC	Number (Single)	4 bytes
I_Sum5_tramp_fitted_FRC	Number (Single)	4 bytes
I_CalculatedBU_FRC	Number (Single)	4 bytes
Tc101_PredAct	Number (Single)	4 bytes
Ba141_PredAct	Number (Single)	4 bytes
Cs138_PredAct	Number (Single)	4 bytes
Ba139_PredAct	Number (Single)	4 bytes
Sr92_PredAct	Number (Single)	4 bytes
Tc99m_PredAct	Number (Single)	4 bytes
Sr91_PredAct	Number (Single)	4 bytes
Np239_PredAct	Number (Single)	4 bytes
Mo99_PredAct	Number (Single)	4 bytes
Te132_PredAct	Number (Single)	4 bytes
Ba140_PredAct	Number (Single)	4 bytes
Te129m_PredAct	Number (Single)	4 bytes
Sr89_PredAct	Number (Single)	4 bytes
Cs134_PredAct	Number (Single)	4 bytes
Sr90_PredAct	Number (Single)	4 bytes
Cs137_PredAct	Number (Single)	4 bytes
Sol_Sum15_fitted	Number (Single)	4 bytes
Sol_Sum15_tramp_fitted	Number (Single)	4 bytes
Delta_Zr95	Number (Single)	4 bytes
Damage_Zr95	Number (Single)	4 bytes
INPO_FRI_SampleValue	Number (Single)	4 bytes
BU_CsRatio	Number (Single)	4 bytes
Power_Fraction	Number (Single)	4 bytes
Sample_RPF	Number (Single)	4 bytes
Sample_BU	Number (Single)	4 bytes

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